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Canadian Mining Institute

1911

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VOLUME XIV

"The Institute as a body shall not be responsible for the statements and opinions advanced in the papers which may be read or in the discussions which may take place at its meetings."—*By-Laws, Par. 48.*

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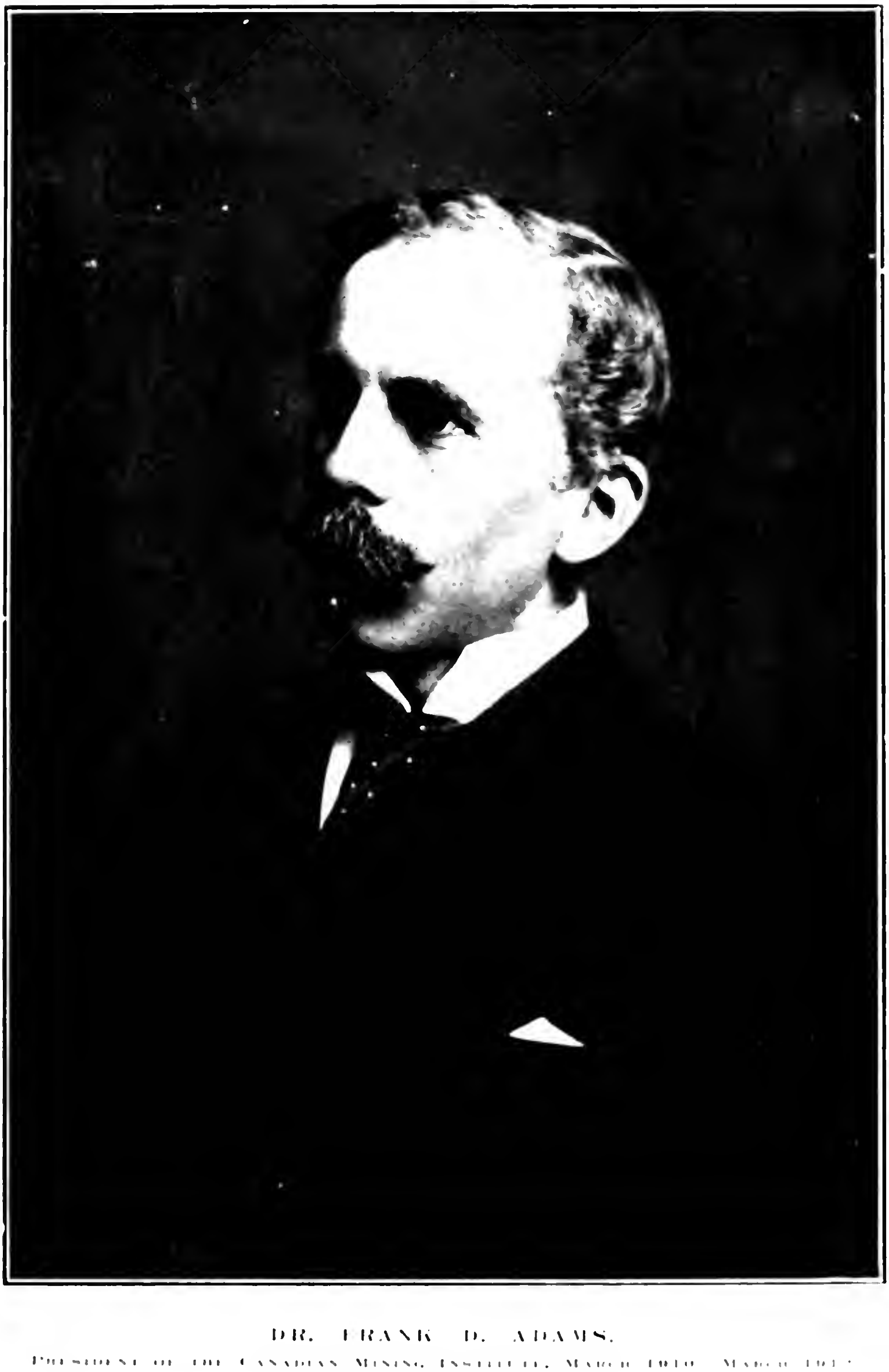
ROOMS 3 AND 4 WINDSOR HOTEL, MONTREAL, JANUARY 1912.



DR. FRANK D. ADAMS.

President of the Canadian Mining Institute, March 1910 – March 1911

V

CANADIAN MINING INSTITUTE

List of Officers and Members of Council since the Establishment of the Institute showing the years during which office has been held.

PRESIDENT

Adams, F. D., 1910, 1911.
Coste, Eugene, 1903, 1904.
Fergie, Charles, 1901, 1902.
Fowler, S. S., 1900.
Hardman, J. E., 1898–99.
Keffer, Frederic, 1907.
Miller, Dr. W. G., 1908, 1909.
Smith, G. R., 1905, 1906.

VICE-PRESIDENT

Adams, Dr. F. D., 1901, 1902, 1903, 1905, 1906.
Barlow, Dr. A. E., 1908, 1909, 1910, 1911.
Blue, John, 1898–99.
Cantley, Thomas, 1905, 1911.
Carlyle, W. A., 1898–99.
Chambers, R. E., 1903, 1904.
Coste, Eugene, 1902.
Dawson, Dr. G. M., C.M.G., 1898.
Dawson, Dr. G. M., C.M.G., 1898–99.
Donkin, Hiram, 1899, 1900.
Drummond, Geo. E., 1899, 1900, 1908, 1909.
Duggan, G. H., 1905, 1906, 1907.
Fergie, Chas., 1898, 1899, 1900.
Fraser, Graham, 1901, 1902.
Goodwin, W. L., 1905.
Hedley, R. R., 1901, 1902.
Hobson, J. B., 1903, 1904.
Hodges, A. B. W., 1910, 1911.
Keffer, F., 1905, 1906.
Kirby, E. B., 1904.
Leckie, R. G., 1905, 1906.
Leonard, R. W., 1910, 1911.
McArthur, James, 1900, 1901.
Miller, Dr. W. G., 1907.
Obalski, J., 1909, 1910.
Porter, Dr. J. Bonsall, 1907, 1908.
Robertson, W. F., 1907, 1908, 1909.
Smith, G. R., 1903, 1904.

COUNCILLORS

Adams, F. D., 1899, 1900, 1904, 1907, 1908.
Aldridge, W. H., 1905, 1906, 1907.
Bancroft, J. A., 1911.
Barlow, Dr. A. E., 1905, 1906, 1907.
Bennett, B., 1902, 1903.
Blakemore, Wm., 1898–9.
Blaylock, S. G., 1910, 1911.
Blue, Archibald, 1898–9.
Blue, John, 1905, 1906.
Brent, Charles, 1899, 1900.
Brewer, Wm. W., 1908, 1909.
Brigstocke, R. W., 1909, 1910, 1911.
Brock, R. W., 1907, 1908, 1909, 1910, 1911.
Brown, J. Stevenson, 1909, 1910.
Browne, David H., 1907, 1908.
Bryce, R. A., 1910, 1911.
Cantley, T., 1903, 1904, 1905, 1906, 1909, 1910.
Chambers, R. E., 1901, 1902.
Cirkel, F., 1904.
Cole, Arthur A., 1908, 1909, 1910, 1911.
Coll, C. J., 1905, 1906, 1909, 1910.
Corkill, E. T., 1911.
Coste, Eugene, 1899, 1900.
Cowans, J. R., 1899, 1900.
Craig, B. A. C., 1905, 1906, 1907.
DeKalb, Courtenay, 1901, 1902.
Denis, Theo., 1911.
Dimock, C., 1898–9.
Donkin, H., 1898–9.
Donnelly, J., 1909, 1910, 1911
Dresser, J. A., 1910, 1911.
Drummond, Geo. E., 1898–9.

COUNCILLORS—*Continued.*

Drury, H. A., 1908, 1909.
Duggan, G. H., 1903, 1904.
Dulieux, E., 1911.
Fergie, Chas., 1908, 1909, 1910, 1911.
Fowler, S. S., 1898, 1899.
Fraleck, E. L., 1909.
Fraser, Graham, 1904.
Galt, E. T., 1899, 1900.
Gilman, E. W., 1907, 1908.
Gilpin, Dr. E., 1903, 1904.
Goodwin, Dr. W. L., 1903, 1904.
Gray, F. W., 1911.
Gwillim, J. C., 1905, 1906, 1907, 1908.
Hardman, John E., 1908, 1909.
Haultain, H. E. T., 1907, 1908, 1909, 1910.
Hay, Col. A. M., 1905, 1906, 1907.
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Hobson, J. B., 1898, 1899, 1901, 1902.
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Kerr, D. G., 1903, 1904.
Kirby, E. B., 1900, 1901, 1903.
Kiddie, Thos., 1905, 1906, 1907.
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Leckie, R. G., 1898–9, 1901, 1901.
Lewis, James F., 1900, 1901.
Libby, W. L., 1898–9, 1902.
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Little, W. F., 1901, 1902.
Loring, Frank C., 1898–9.
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McArthur, James, 1898–9.
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McConnell, R. G., 1900, 1901.
McEvoy, J., 1904, 1905, 1906, 1907, 1908, 1910, 1911.
McNab, A. J., 1908, 1909.
McNaughton, G. F., 1900, 1901.
Meissener, C. A., 1899, 1900, 1905.
Merritt, W. Hamilton, 1898–9.
Miller, Dr. W. G., 1904, 1905, 1906.
Obalski, J., 1898, 1905.
Parrish, S. F., 1903, 1904.
Parsons, W. F. C., 1908.
Penhale, J. J., 1898–9, 1910, 1911.
Poole, H. S., 1900, 1901.
Porter, J. Bonsall, 1902, 1903, 1905, 1906, 1909, 1910.
Robb, D. W., 1901, 1902, 1905, 1906, 1907, 1908.
Robbins, Frank, 1902.
Robertson, W. F., 1904.
Shields, Cornelius, 1902, 1903.
Silvester, G. E., 1911.
Sjostedt, E. A., 1902, 1903.
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Smith, J. Burley, 1900, 1901.
Smith, O. B., 1908, 1909.
Snyder, F. T., 1898–9.
Stewart, R. H., 1908, 1909.
Tonkin, J. H., 1903.
Turner, A. P., 1902, 1903.
Tyrrell, J. B., 1908, 1909, 1910, 1911.
Whiteside, O. E. S., 1910, 1911.
Williams, H. J., 1903, 1904, 1905, 1906.
Willmott, A. B., 1905.

SECRETARY

Bell, B. T. A., 1898, 1899, 1900, 1901, 1902, 1903.
Coste, Eugene (Acting Secretary), 1904.
Lamb, H. Mortimer, 1905, 1906, 1907, 1908, 1909, 1910, 1911.

TREASURER

Brown, J. Stevenson, 1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907, 1908.
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CANADIAN MINING INSTITUTE

PROCEEDINGS OF THE THIRTEENTH ANNUAL MEETING

QUEBEC, March 1st, 2nd, & 3rd, 1911.

The Thirteenth Annual General Meeting of the Institute was held at the *Chateau Frontenac,* Quebec, on Wednesday, Thursday and Friday, March 1st, 2nd and 3rd, 1911, the President, Dr. Frank D. Adams, in the chair. The attendance was in the neighbourhood of a hundred and twenty and included the following guests:—Dr. James Douglas and Dr. A. R. Ledoux, representing the American Institute of Mining Engineers; Mr. F. L. Garrison, representing the Institution of Mining and Metallurgy; Mr. W. R. Ingalls and Dr. J. F. Kemp, representing the Mining and Metallurgical Society of America; Dr. D. T. Day, representing the United States Geological Survey; Mr. G. S. Rice, representing the U. S. Bureau of Mines; Prof. C. H. Richardson, of Syracuse University, Syracuse, N.Y.; Dr. H. Ries, of Cornell University, Ithaca, N.Y.; Dr. A. C. Lane, of Tufts College, Mass.; and Mr. F. L. Nason, of West Haven, Conn.

WEDNESDAY MORNING SESSION.

The members assembled in the Octagon Room of the *Chateau Frontenac*, at 10.30 a.m., and were welcomed by the Hon. C. R. DEVLIN, Minister of Colonization, Mines and Fisheries for the Province of Quebec, who, in the course of an interesting address, expressed the Prime Minister's regrets that he was unable, by reason of pressing Parliamentary duties, to be present, and in that gentleman's name and his own bade the Institute welcome to the capital. Mr. Devlin stated that he himself had travelled several hundred miles in order to be in attendance at the annual meeting of the Institute, in whose work he took a warm interest. In fact, he was under deep obligation to the Institute in that its Council had, after its advice had been solicited, recommended the appointment of Mr. T. DENIS, to the Superintendentship of Mines for the Province, and to whose worth and ability he was pleased to testify.

Mr. DEVLIN added: "I have, I think, already demonstrated, by practical means, my appreciation of the services and sympathy with the aims of the Canadian Mining Institute. When, however, I am in a position to increase the amount of the present annual grant made by the Quebec Government to the Institute, it will afford me very great pleasure to do so. It must be recognized, however, that the development of the Province's mineral resources has so far been limited, and that our revenue from mines at present is not great as compared with that of other Provinces of the Dominion. But I am firmly convinced of the advisability of stimulating mineral development and if our present revenue from the mining industry is inadequate, then we should devote, I believe, revenues from other sources towards the encouragement of exploitation and development of our mineral resources. On this conviction, I induced our government to provide for the expedition to the Chibougamon region and for other expeditions last summer. The information secured as a result of these expeditions will undoubtedly prove of the greatest value. The same policy will be followed this year. Three expeditions under the direction of highly qualified mining geologists will be sent into promising, if little explored, areas to report for the benefit of the prospector and the miner; and thus we hope in due course to see established in the Province of Quebec a mining industry no less important and no less flourishing than that of which the sister Province of Ontario has such good cause to be proud."

THE PRESIDENT in responding to the address of welcome said: —"I am sure we all feel very grateful to Mr. DEVLIN for his presence here to-day. I personally can testify that no Minister of the Crown in Canada takes a keener interest than he in the work of the Canadian Mining Institute. The grant which by his recommendation has been made to the Institute, has been given without any provincial restrictions as to its expenditure, but has been granted to aid in the furtherance of the Institute's work in the interests of mining in the Dominion as a whole. I believe I voice the sentiments of this meeting in expressing grateful acknowledgments to Mr. DEVLIN for an interest in the Institute both sincere and cordial."

The President then delivered the following address:—

Presidential Address.

"It affords me great pleasure to welcome the members and guests of the Canadian Mining Institute to the ancient city of Quebec, on the occasion of this our thirteenth Annual Meeting. It was in the Province of Quebec, it is interesting to recall, that the first step was taken towards the establishment of a mining society in this country. I refer to the organization of the Quebec General Mining Association in the year 1890. From this beginning, in reality, sprang the present Canadian Mining Institute; for, following the example set by Quebec, organization on similar lines was inaugurated in the Provinces of Nova Scotia and Ontario, and four years later, in 1894, the associations then in existence, combining, for a specific purpose, constituted themselves as the Federated Canadian Mining Institute. The restricted aim of the new association which continued to maintain provincial distinctions was, however, ere long recognized, and so in 1898 a determination to re-organize on broad, national lines was carried into effect and the Institute whose object is the promotion of the interests of the mining industries of Canada, from the Atlantic to the Pacific, and whose present membership is upwards of a thousand, was duly formed.

"But realizing the vast territory over which this membership is scattered, the consequent difficulty of frequent representative gatherings at any one centre and the desirability of maintaining interest in the work of the society in localities remote from headquarters, a policy of establishing local branches in outlying sections and districts was proposed and adopted in the year 1902. This policy has proved most effective in widening the scope of the Institute's influence and usefulness, while at the same time the integrity of the organization as a national institution continues to be maintained. The present active branches of the Institute are those at Sherbrooke, Montreal, Kingston, Toronto, Cobalt and a western branch or section, whose membership includes members of the Institute resident in British Columbia and Alberta. The establishment of a branch at the new mining camp of Porcupine, Ontario, is also contemplated.

"While branches thus serve a useful purpose, the Council now considers, in view of the very considerable increase of membership in Western Canada of late years, that further steps should be taken in the interests of members residing in the Pacific provinces of Alberta and British Columbia who, for obvious reasons, can only on rare occasions attend the Annual Meetings of the Institute in Eastern Canada. It is, therefore, proposed, to provide in future for occasional or regular semi-annual general meetings of the Institute, in the summer or early autumn months, at some centrally situated point in the West; and it is hoped that these summer meetings will be attended not only by Western members but also by a very considerable number of members resident in Eastern Canada.

"Possibly in no direction have the activities of the Institute been engaged to better purpose than in publicly voicing the opinions of the mining communities with a view to influencing legislation. Thus in recent years representations have been repeatedly and successfully made to both the Federal and Provincial Governments on questions affecting or likely to affect the industry; and special reference may be here appropriately made to a very important work of this nature undertaken during the past year by the Legislative Committee of the Institute. It has long been a matter of just complaint that the conditions in respect of the granting of title to mining lands subject to Federal control were aggravating and unsatisfactory, since they were fixed not by Statute but by Order in Council, and consequently unstable and uncertain. Acting then, under the direction of the Council, the Legislative Committee interviewed the Prime Minister and the Minister of Mines in April last and represented to those gentlemen the importance of placing a mining law on the Statutes of the Dominion regulating the issue of title to mineral lands. The question was also debated by the Committee before the Select Standing Committee on Mines and Minerals of the House of Commons and the Government having consented to introduce a bill, invited the Institute to suggest the principles on which it should be formulated. Certain recommendations were in consequence made by the Institute's committee and being approved by the Council were duly submitted to the authorities; whereupon the Minister of Mines appointed Mr. J. M. Clark, K.C., of Toronto, to draft a bill for early submission to Parliament on the lines suggested. I may, therefore, be permitted to express the opinion that the Institute is deeply indebted to the committee in charge of this undertaking and to its chairman, Mr. G. G. S. Lindsey in particular, for the very valuable service they have rendered the mining industry by their successful endeavours in this direction.

"Before leaving the subject of the Institute's efficiency I should like to call attention for a moment to the present value of the society's publications. It is not, in fact, too much to say that the Institute's Transactions compare favourable with those of any similar organization in the world; and this is the more a matter for congratulation when it is remembered that relatively speaking our membership is small. The Transactions, moreover, now constitute one of the chief and best channels by which information concerning the mineral resources of the Dominion is made known to the public both at home and abroad. Again, it must have been apparent to members, that the standard of excellence attained in recent issues of the Annual Volume or Journal is a very high one, and not only has there been a very noticeable increase in bulk, but the papers now published are generally of a distinctly higher character than those of former years.

"Finally, it is gratifying to direct attention to the very cordial and friendly relation existing between the Canadian Mining Institute and the Institution of Mining and Metallurgy. This was further marked last year (1910) by the appointment, for the first time, of a student member of the Institute to one of the post-graduate courses of study recently established by the Institution of Mining and Metallurgy.

"In this regard it is to be noted that nomination for the distinction was delegated to the Council of the Institute, who greatly appreciate this evidence of interest and goodwill on the part of the Institution.

CANADIAN MINING PROGRESS.

"Turning now to the main events of the year in connection with mining developments in the Dominion, it is gratifying to note a further considerable increase in mineral production, the returns for 1910 showing a value of output of $105,000,000—the largest production in the history of the industry in Canada. In reference to the subject of mineral statistics, attention may well be called to an interesting departure on the part of the Department of Mines of British Columbia, in publishing in January of this year a preliminary review and estimate of the mineral production of that province in advance of the full report, which is usually published about the month of June. In general, conditions during 1910 appear to have been satisfactory; and, as the returns indicate, fair progress in most branches of industry has taken place. Among the mineral-producing Provinces, Ontario now occupies the premier position as regards value of annual output, attributable chiefly, of course, to the silver yield from Cobalt, which is at the present time the greatest individual silver producing area in the world—a fact that may be properly a matter of pride to Canadians.

"The year was likewise notable for the commencement of actual development in two new areas, the Porcupine district in Ontario and the Portland Canal District in British Columbia. The reports originally circulated concerning the extraordinary richness of the latter area appear, however, to have been unduly optimistic. It would nevertheless seem that there are in the vicinity of Stewart a number of promising prospects, which may presently become productive. On the other hand, the developments in Porcupine have in several instances proved eminently encouraging and much capital from abroad has already been invested in this district. An unfavourable factor, to be noted, has been the absurdly inflated, often quite prohibitive, prices demanded for undeveloped prospects; but this, of course, is a mere phase common enough in new fields.

"In the West, the rapid progress of the coal mining industry and the general extension of actual colliery as well as development operations are of particular interest.

"In the Province of Quebec, asbestos mining continues to rank first among local mining industries, production during 1910 attaining to a new high level, which in view of the constantly increasing uses for asbestos, will doubtless be maintained.

"One result of an increase of population in Canada, now taking place so rapidly, will be the utilization of resources heretofore in a large measure neglected. These resources include clay and building stones and it is, therefore, gratifying to note that a careful preliminary study of the clays of the Dominion, under the direction of the Geological Survey, is being made with a view to a determination of the value of these minerals for the several purposes to which they may be applied in the arts and manufactures; while a similar investigation in respect of building stones is being carried on by the Mines Branch of the Federal Department of Mines.

"Of the many valuable contributions made by Sir William Logan to our knowledge of the Dominion, one in particular was his recognition of the great system of rocks, which he named the Huronian System, from their extensive development along the north shore of Lake Huron. Recognising and indicating this great belt of Huronian rocks as a promising area for the discovery of valuable minerals, he traced the belt in question north-eastward through what were, at that time, the primæval forests of the Dominion. In the geological map of Canada, published in 1882 this belt is shown extending to Lake Abitibi and there forking, one arm branching to the north of Lake Superior and a much longer arm continuing over into the Province of Quebec and reaching north-eastward to the south of Lake Mistassini. Logan's opinion concerning the highly promising character of this belt of rocks has been amply borne out by subsequent exploration, for on it is situated not only the old Wallace mine (in which nickel was first discovered in this portion of the Dominion) and the Bruce mine (from which so much copper was taken during Logan's lifetime), but also the great nickel deposits which were subsequently discovered at Sudbury, the silver camp at Cobalt and the deposits at Larder Lake, Gowganda and Porcupine. That portion of this great belt in the Province of Quebec has not as yet yielded deposits of such value as those mentioned in Ontario; but indications of the presence of valuable minerals have already been discovered at a number of points, including reported discoveries in the Chibougamau District. In order to determine the real value of these discoveries in that region, the Quebec Government last summer adopted the very commendable step of appointing a commission of geologists and mining engineers of ability and reputation, under the leadership of Dr. A. E. BARLOW, to proceed to the Chibougamau District and make a thorough and detailed examination of that area. The report of the commission was to the effect that the occurrences hitherto discovered and described from this part of the

Dominion do not warrant the expenditure of the large sum of money requisite to build a railway to that somewhat remote region, has saved the Quebec Government a very large expenditure that might otherwise have been made, and may now be devoted to the very much better purpose of carrying on additional examinations of other tracts of this promising country, under the leadership of properly qualified geologists and mining engineers. It is understood that the Government of the Province of Quebec contemplate commissioning several such parties during the coming summer and there is every reason to believe, as time goes on and the country becomes thoroughly prospected, camps similar to Sudbury, Cobalt or Porcupine will be developed in the Huronian belt of the Province of Quebec; although, unfortunately, a not inconsiderable portion of this area is deeply covered with clay which while it may be of value to the agriculturist, greatly restricts the possibility of prospecting the districts where it occurs.

"There is every reason to believe that when the nepheline-syenite deposits, holding, as has been proved, such abundant supplies of corundum in the Craigmont district of Eastern Ontario, are traced across into the Province of Quebec—into which province they can undoubtedly be followed—they will there be found to contain additional deposits of this valuable abrasive. May I add that the Government of the Province of Quebec is to be congratulated on having appointed so excellent an officer as Mr. Théophile Denis, M.Sc., to assume, in the capacity of Superintendent of Mines, general direction of these investigations; while the Province is no less fortunate in a Minister of Mines possessing the Hon. Mr. Devlin's acumen and enlightenment.

"The position of Canada as one of the great mineral-producing countries of the world has also, during the past year, been recognised by the International Congress of Geologists in their decision to hold the next meeting of this Congress in Canada. This will take place in August, 1913. The Congress meets in Canada at the joint invitation of the Government of Canada and of the Canadian Mining Institute, and it is anticipated that there will be an attendance of geologists and mining engineers from all parts of the world, to the number of about one thousand. The committee in charge of the arrangements for the Congress is dependent on the support and co-operation of the members of the

Institute in carrying out the plans now being considered for the entertainment of the visitors and to afford them the opportunity of surveying the mineral resources of the Dominion from the Atlantic to the Pacific.

"In conclusion, I may be permitted to voice the views of the Institute in the expression of our high appreciation of the efforts that the Government of the Dominion, through the agency of the Commission of Conservation, is making for the thorough investigation of the various problems in relation to the conservation of the various natural resources of the country. With the increased drain year by year on our natural resources the public now clearly appreciate the necessity of conserving and, so far as possible, perpetuating the natural resources by the adoption of reasonable means to prevent waste and to encourage development along rational lines. This movement, therefore, should have the support of every citizen of the Dominion."

National Commission on Conservation.

Adverting to the remarks of the President touching the work of the National Commission on Conservation, Mr. A. M. Hay moved the following resolution:—

Resolved: that the Canadian Mining Institute in Annual Meeting assembled desires to express its appreciation of the work of the Commission of Conservation. As, with the increased drain which is being made year by year on the natural resources of Canada, the Institute appreciates the necessity of conserving and, as far as possible perpetuating, the country's natural resources by the adoption of reasonable means to prevent waste and to encourage development along rational lines.

"And be it further resolved that a copy of this resolution be forwarded to the Hon. Clifford Sifton, Chairman of the Commission of Conservation at Ottawa."

The resolution, which was adopted unanimously, was seconded by Mr. J. B. Tyrrell who in speaking to the motion said: "There can be no question that the task assumed by this Commission of educating the public to the necessity of conserving the natural resources of the country is a most important one and its propaganda should have a most far-reaching and beneficial effect.

I am certain that the Hon. CLIFFORD SIFTON, Chairman of the Commission, and his able lieutenant Mr. JAMES WHITE, who occupies the post of Secretary on the Board, have the interests of Canada very much at heart; and it is fitting and proper, therefore, that the Canadian Mining Institute should take cognizance of their efforts."

The resolution was adopted unanimously.

REPORT OF COUNCIL, 1910.

The Report of the Council and Financial Statement for the year ending December 31st, 1910, as follows, was adopted:

In reviewing the activities of the Institute for the year ending December 31st, 1910, the Council takes the opportunity of congratulating the members on the present satisfactory condition of the affairs of the Society; on the expansion of its scope of influence and usefulness; the well maintained increase in its membership, and the manifest improvement in the value of its publications. The interest displayed in the meetings is strongly evinced by the statement that the registration at the Annual General Meeting in Toronto in March showed an attendance of over two hundred and thirty members and guests; or a representation of about thirty per cent of the total membership. Considering the vast area over which the membership is scattered, so considerable an attendance is remarkable and in the highest degree gratifying. The meeting of the Western Branch in Vancouver in February last was also well attended, and the papers read stimulated discussions of an exceptionally valuable character. A largely attended meeting of the Cobalt Branch was held in July, at which Prof. Robt. H. Richards, the distinguished authority on ore-dressing, delivered a lecture on this subject, having special reference to the conditions obtaining in the Cobalt District.

The Special contributors to the Transactions this year, and to whom thanks are due, include Prof. Richards, for his comprehensive paper on the "Development of Hindered Settling Apparatus"; Dr. F. L. Ransome, Mr. B. B. Lawrence, Dr. James Douglas, and Dr. Heinrich Ries. It should also be noted that Dr. J. D. Irving delivered an exhaustive address on the subject of "Replacement Deposits", at the Annual Meeting; but by reason of other pressing duties has not found leisure in the interim to transcribe his notes for publication. It is hoped, however, that this contribution in printed form will be available to members in the near future.

In view of the considerable augumented cost of publishing the Transactions, partly ascribable to the increased bulk of the annual volume of Transactions, to the publication of a quarterly bulletin, and also to the general advance in prices charged for printing, the Council, recognizing that retrenchment in some direction was necessary, decided to discontinue the practice of binding the annual volume of Transactions in half-leather. In future, therefore, the volumes will be issued in paper covers. Provision is made, however, that members desiring it shall receive the volume in half-leather binding upon payment of one dollar per annum in addition to the regular membership subscription.

Unquestionably the most important work undertaken by the Institute during the year has been the endeavour to induce the Dominion Government to act on the recommendations of the Select Standing Committee of the House of Commons on Mines and Mining. These recommendations were (1) that there be assigned to the Mining Department the administration of mines, including the issue of title thereto, and of all Mining Laws; and (2) that an Act be passed consolidating all the laws relating to mines under Federal control.

Immediately after the Annual Meeting the Council appointed a committee under the Chairmanship of Mr. G. G. S. Lindsey, to represent the Institute, and to take such steps as might be expedient to properly impress on the Government the need for early and prompt action along the lines indicated. The Committee, therefore, proceeded to Ottawa, on Monday, March 21st and waited on the Premier, to whom the issues were fully submitted, special stress being laid on the importance of providing that prevision of issue of title to mining lands controlled by the Federal Government, be fixed by Statute enactment, instead of by regulations subject to arbitrary and frequent change by orders in council. The Committee also pointed out that the present opportunity was favourable to the framing of a mining law for the Dominion that would be so just and right in principle as to recommend itself for universal adoption in Canada, and expressed the hope that the introduction of such a bill would be the first step towards the accomplishment of this uniformity, which was very much desired by those interested in the development of our mining resources. The Premier's reception of the Committee's views was entirely courteous and friendly, and before the close of the conference gave a definite assurance that a transference of the administration of mining lands from the Department of the Interior to the Department of Mines would be made, and added the suggestion that the Canadian Mining Institute undertake the drafting of a mining law which could be introduced to and considered by Parliament at the next session. The Committee consulted with the Hon. Wm. Templeman, Minister of Mines, and with members of the Parliamentary Committee on mines on this point. No definite action was taken by the Government until Wednesday December 14th, when the Committee having drafted certain recommendations embodying what in their judgment should be adopted as the basis of a mining law, again went before the Parliamentary Committee to urge immediate action. These recommendations which had previously been endorsed by the Council of the Institute are as follows:

"(1) That the title to be required should be a lease for ninety-nine years for all purposes.

"(2) That the rental should be based upon the acreage and paid in advance at the rate of one dollar per acre per annum. Work done on any claim to the extent of the rental, but only where work alone amounts to at least $200.00 in any one year, is to be received in lieu of rental for that year.

"(3) That, in addition, royalties at the rates at present provided, be paid, (it to be made clear what the general clause in regard to royalties in the existing statute means).

"In the case of coal the present royalty, five cents per ton (2000 lbs) should prevail up to the year 1930 (this date is given because the existing 21 years' leases based on the five cent royalty expire at that time), and after 1930, and up to the end of the present century the royalty should be ten cents per ton.

NOTE:—Existing lessees should be permitted to exchange for leases under the new statute.

"(4). The prospector shall not be obliged to make discovery of mineral in place to the satisfaction of anyone, but having made what by him is believed to be a discovery of mineral in place, he is to be permitted to stake out a claim and then record it in the Government recording office at a nominal fee, on doing which a lease is to be issued to him, which lease is to be perfectly free from any condition dependent on the opinion or reports of officials.

"(5). A license fee shall be required of persons applying for the lease of mining lands from the Crown, and a prospector must either obtain a license to prospect before going into the field, or qualify in this respect before recording a claim."

The argument in favour of the adoption of the leasehold system of mining land tenure was strongly presented to the Parliamentary Committee by Mr. Lindsey, and this as well as the other recommendations put forward were approved. The Minister of Mines having pointed out that under existing conditions the question arose whether the Minister of the Interior or of Mines should be responsible for the preparation of the Bill, the point at issue was referred to the Premier who decided that the responsibility rested with the Minister of Mines. In consequence Mr. Templeman immediately instructed Mr. J. M. Clark, K.C., of Toronto, to draft a Bill on the lines suggested by Mr. Lindsey's committee.

The Council consider that the Committee is to be heartily congratulated on its success in advancing the business with which it was entrusted to the present stage, and confidently anticipate that as a direct result of the committee's exertion, a mining law which will be highly acceptable to the mining community, will, in the near future be placed on the statutes of the Dominion.

It is also satisfactory to record that two resolutions adopted by the Western Branch, one advocating the removal of Customs duty from rescue apparatus for use in coal mines, and the other the establishment of telegraphic communication with the Portland Canal district, have been acted on by the Federal Government.

Two important international meetings took place during the year in Europe, namely, that of the International Geological Congress in Sweden, and the International Mining Congress at Düsseldorf, Germany. The Institute was represented at the former by the President, Dr. Frank D. Adams of Montreal, who was appointed one of the vice-presidents at the Congress, and contributed several valuable papers, dealing with Canadian geological conditions, to the proceedings. The President, on behalf of the Institute, also invited the Congress to hold their next meeting in Canada, and this invitation which was made conjointly by the Dominion Government and the Canadian Mining Institute, having been accepted, the Meeting will be held in Canada during the summer of 1913. The Council takes this opportunity of bespeaking the interest and co-operation of the membership in the organization arrangements which have been already initiated.

The meeting of the Congress in Canada which will be attended by probably a thousand of the most eminent geologists from all parts of the world, will be an event of first rate importance. Highly beneficial results of both a scientific and practical character may be confidently looked for, and the council is most desirous that the Institute should not fail to do full justice to the occasion.

The meeting of the International Mining Congress was held at Düsseldorf, Germany, during the last week in June. The Institute was officially represented by the Secretary, who presented a paper on "The Mineral Resources and Industries of Canada," which has been widely circulated. The Secretary also delivered an address illustrated by lantern slides, on the same subject in England, and several interviews with him were published in the London papers. As a result of a suggestion made to the Chief Clerk in the office of the High Commissioner for Canada, persons applying to that official for specific information respecting mines and mining in this country, have been advised to communicate with the Institute, and during the part few months numerous enquiries have been received and replies duly sent.

The effect of the by-law adopted at the last Annual Meeting, providing for the admission of members of the Institution of Mining and Metallurgy to the Institute at a reduced annual subscription, has been to further strengthen the relationship between the two organizations; and at a Banquet tendered by the Council of the Institution to members of Council and officials of the Institute in London in July last, reported in Quarterly Bulletin, C.M.I. No. 12, page 3, appreciative reference is made by the President of the Institution to this action on the part of the Institute. The desire of the Institution to promote close and friendly relations, is also evinced by the extension of the post-graduate courses under the auspices of the Institution, to Canada, and on the recommendation of a committee of the Council, Mr. G. J. McKay, a graduate of the School of Mining, Kingston, was awarded one of the Institution's Scholarships last spring, and has since left to follow the prescribed course in South Africa. A proposal to hold a joint meeting of the Institution and the Institute in Canada during the winter of 1911–12 is meanwhile under discussion, and it is hoped that arrangements to that end would shortly be completed.

MEETINGS.

The Twelfth General Annual Meeting of the Institute was held at the King Edward Hotel, Toronto, on March 2nd, 3rd, and 4th, 1910. As already mentioned, the attendance was the largest yet recorded since the inception of the Institute. Other meetings held during the year were at Vancouver, B.C., on February 25th, at Grand Forks, B.C., on May 26th, at Sherbrooke, Que., on May 27th, at Cobalt, Ont., on July 6th, at Montreal on November 4th, and at Toronto on December 2nd. Five regular and two special meetings of Council have been held during the year.

PUBLICATIONS.

The papers presented at the Annual Meeting, together with those read at the Branch Meetings, and also others transmitted direct to the Secretary, in all 41 papers, two of which were contributed by non-members upon the invitation of the Council, two contributed by corresponding members, thirty-three by members, and four by student members, together with the discussions thereon, are published in Vol. XIII. of the Journal of the Institute, which has been distributed to members in good standing. Four Bulletins, representing 796 pages of printed matter, have also been published and distributed during the year.

BRANCHES.

The meetings at Vancouver and Grand Forks, B.C. held under the auspices of the Western Branch, were well attended, and interest in this Branch is well maintained. At the Meeting of the Cobalt Branch in July an attendance of upwards of one hundred members and guests is reported. The feature of the Toronto Branch meetings is a fortnightly luncheon, after which matters of general interest as affecting either the mining industry or the Institute are frequently discussed. The Toronto Branch has also on several occasions entertained distinguished engineers from abroad at their periodical gatherings. The reorganization of the Sherbrooke Branch established in 1900, is a further matter for congratulation, and has resulted in a considerable increase of membership from the Eastern Townships of the Province of Quebec.

LIBRARY.

A special effort has been made to increase the efficiency of the library, and a considerable appropriation was devoted this year to the purchase of new books, bookcases and to binding. Sets of reports, society transactions, or reference works, from which early numbers were found to be missing, have been completed as far as possible, and in all some 300 volumes have been added to the shelves. An abridged catalogue of the books in the library has been printed in No. 12 of the Bulletin, and members have been advised on what terms they may borrow books, and informed that the Secretary will undertake to make searches, prepare bibliographies and abstract information on special subjects upon request. Advantage has already been taken of these provisions. Use, to a considerable extent, has also been made of the library and reading room by visitors from abroad.

SECRETARY'S OFFICE.

The following returns are taken from the Secretary's records for the year ending December 31st. 1910:

Letters received	2,039
Letters sent, notices, etc.	5,477
Circulars issued.	7,600
Publications issued	6,525

STUDENTS' COMPETITION AND AWARDS.

Eight papers were submitted this year by student members in competition for the Institute's annual awards. After receiving the report of the judges namely, Dr. A. E. Barlow, Mr. J. C. Murray and the Secretary, the Council awarded the President's Gold Medal to Mr. G. L. Burland, of McGill University, Montreal, for his paper entitled "Longwall Mining and Emery Pit, Dominion No. 10, Reserve C.E."; while a cash prize of $50, was equally divided between Mr. A. M. Bateman of the School of Mining, Kingtson, Mr. J. J. McEachern of the School of Mining, Kingston, and Mr. A. G. Haultain of McGill University, Montreal. The prize winning papers (with the exception of that by Mr. Burland, which is withheld for the present) as well as a paper contributed by Mr. G. A. Gillies, of McGill University, have been published in Vol. XIII of the Transactions.

COMMANS–FRECHEVILLE–MARRIOTT PRIZE.

The prize of two hundred and fifty dollars offered by Messrs R. E. Commans, William Frecheville, and H. F. Marriott of London, England, for the best paper dealing with mining or metallurgical progress in Canada between October 1908 and October 1909, contributed to the Transactions of the Institute prior to January 1st. 1910, was divided equally between Mr. H. H. Yuill, for his paper on "The Hosmer Mines, B.C.," and Mr. Frank B. Lathe, for his paper on "The Granby Smelter."

MEMBERSHIP.

The membership now numbers, inclusive of all classes, nine hundred and seventy four members.

The accessions during the year were as follow:

Honorary members	1
Corresponding members	2
Ex-officio members	5
Life members	3
Members	71
Associates	22
Students	5
	109

DEATHS.

The Council records with profound regret the deaths during the year of the following members:

MEMBERS.

- Grundy, Frank, Sherbrooke, Que.
- Hardy, G. D., Cobalt, Ont.
- Reed, Dr. James, Reedsdale, Que.
- Wiley, H. A., Toronto, Ont.

The resignations of the following members and associates have been accepted:

MEMBERS.

- Anderson, W., Rossland, B.C.
- Farquhar, J. B., Vancouver, B.C.
- Gamey, R. R., Toronto, Ont.
- Hardinge, H. W., New York City, U.S.A.
- Harris, J. M., Sandom, B.C.
- Kaye, Alex., Vancouver, B.C.
- Miller, Spencer, New York City, U.S.A.
- Mills, S. D., Toronto, Ont.
- Parkhurst, F. S., Niagara Falls, N.Y.
- Powell, J. W., Coleman, Alta.
- Sands, J. M., Rossland, B.C.
- Sharp, B. N., Orient, Wash., U.S.A.
- Sproule, G., Montreal, Que.
- Stock, H. H., Swanton, Pa., U.S.A.

ASSOCIATES.

- Bowers, A. E., Northport, Wash., U.S.A.
- MacKenzie, A. B., Rossland, B.C.
- Morrison, G. F., Toronto, Ont.
- Pringle, Clive, Ottawa, Ont.
- Rugh, W. S., Rossland, B.C.

STUDENTS.

- Carr-Harris, A., Mexico.

(Signed) H. MORTIMER-LAMB,
Secretary

FINANCIAL STATEMENT.

DISBURSEMENTS DURING YEAR ENDED DEC. 31ST, 1910.

Publications—			
Printing & Binding Trans., Vol. XII. (Part)		$1,641.84	
Packing, Postage & Express		75.00	
Printing, & Binding Trans., Vol. XIII. (Part)		2,283.64	
Packing, Postage and Express		61.24	
Editor's salary		1,600.00	
Prizes to students		75.00	
			$5,736.72
Meetings—			
Annual		962.86	
Council		22.00	
Office & Library—			984.86
Salaries to Secretary, Treasurer & Stenographer	$ 3,118.92		
Less, charged to Publications	$ 1,600.00	1,518.92	
Rent		750.00	
Telephone rent		55.00	
Telegrams & Long Distance Telephone		40.82	
Postage		69.55	
Printing & Stationery		237.14	
Travelling Expenses, ordinary		189.10	
Travelling Expenses, Secretary's visit to International Mining Congress, Germany		450.00	
Bank charges		20.68	
Auditing & Special Assistance		55.00	
Sectional bookcases for Library		318.25	
Books		169.03	
Binding, Etc.		185.54	
Insurance (Library & Furniture)	$ 2,000.00	41.00	
Advertising		50.00	
Prize, remitted to Institute in 1909 by Messrs Commans, Frecheville & Marriott		250.00	

Miscellaneous		$19.60	
		————	$4,419.63
Branches—			
Western......................		164.00	
		————	164.00
(This Branch also received a grant of..........	$1,000.00		————
from the B.C. Government.)			$11,305.21

Audited and verified:

P. S. ROSS & SONS,
Chartered Accountants.

W. S. LECKY,
Treasurer.

MONTREAL, Feb. 14th, 1911.

AUDITORS' REPORT.

MONTREAL, Jan. 13th, 1911.

To the President and Members
of the Canadian Mining Institute, Montreal.

Gentlemen:—We beg to report having completed the audit of the Financial Books of your Institute for the year ended 31st, December, 1910.

The monies received on account of the Institute have been verified by checking the stubs of the Receipt Books to the Cash Book. The amounts received have been regularly deposited in the Bank Accounts and the disbursements have been made by cheque and are covered by duly approved vouchers.

The additions of the subsidiary books and the posting of the entries therein to the various Ledger Accounts have been checked in detail and we have seen that they were correctly incorporated in the Financial Statements for the year.

The balances in the Bank Accounts at the close of the year have been verified and further substantiated by certificate from the Bank.

We have certified the Annual Statements as correctly showing the financial transactions of the Institute during the year, and the true position of it at the close thereof as shown by the Books and Records.

Respectfully submitted,
P. S. ROSS & SONS,
Chartered Accountants.

ELECTION OF OFFICERS AND COUNCIL, 1910.

The Secretary announced that only sufficient nominations had been received to fill offices falling vacant on the Council for the ensuing term, and the following gentlemen were therefore elected by acclamation:—

President:

Dr. FRANK D. ADAMS, Montreal, Que.

Vice Presidents:

Dr. A. E. BARLOW, Montreal, Que.
Mr. T. CANTLEY, New Glasgow, N.S.

Councillors:

Dr. J. AUSTEN BANCROFT, Montreal, Que.
Mr. R. W. BROCK, Ottawa, Ont.
Mr. A. A. COLE, Cobalt, Ont.
Mr. E. T. CORKILL, Toronto, Ont.
Mr. THÉO. DENIS, Quebec, Que.
Mr. JOHN DONNELLY, Kingston, Ont.
Mr. E. DULIEUX, Montreal, Que.
Mr. F. W. GRAY, Glace Bay, N.S.
Mr. G. F. SILVESTER, Copper Cliff, Ont.
Mr. J. B. TYRRELL, Toronto, Ont.

STATISTICS OF MINERAL PRODUCTION.

Mr. J. McLEISH, Chief of the Division of Mineral Resources and Statistics, of the Department of Mines, Ottawa, in presenting a statement of the mineral production of Canada for the year 1910, said:

THE MINERAL PRODUCTION OF CANADA IN 1910.

"The total value of the mineral production of Canada, during the calendar year 1910, according to the Preliminary Report on the Mineral Production of Canada 1910,' just issued by the Mines Branch of the Department of Mines, exceeded the sum of $105,-000,000. The statistics would seem to show that the year 1910 was one of exceptional activity in the successful exploitation of Canada's mineral resources. The production is made up from such a great variety of well established mining industries that the record should be particularly gratifying not only to those who are directly interested in the development of the mineral resources of the country, but also to the public at large who indirectly profit thereby.

"Not only is the increase over the production of the previous year a large one, having amounted to $13,209,517, or over 14 per cent., but an examination of the details of production shows that the increase has been fairly well distributed amongst the more important ores and minerals produced in Canada.

"The production of the more important metals and minerals is shown in the following tabulated statement in which the figures are given for the two years 1909 and 1910, in comparative form, and the increase or decrease in value shown.

"It will be observed that an increase is shown in copper production of 4,104,211 pounds, or about 7.8 per cent.; in gold production of $842,680, or 9 per cent.; in pig iron of 43,635 tons, or nearly 9 per cent.; in nickel of 10,988,042 pounds, or 41.8 per cent.; and in silver of 4,453,855 ounces, or 16 per cent. In the case of lead there is shown a decrease of 12,869,916 pounds, or 28 per cent.

"All of the metals, with the exception of gold and lead, show higher production than recorded in any previous year.

"Amongst the non-metallic products there is an increased production of asbestos (excluding asbestic) of 12,329 tons, or 19 per cent.; an increase in coal of 2,295,037 tons, or 22 per cent.; in gypsum of 92,184 tons, or 21 per cent.; in cement of 686,266 barrels, or 16.8 per cent. There is also an increased production in the value of natural gas of $105,585, or 8.7 per cent.; in value of clay products of $1,149,190, or 17.8 per cent.; in value of stone of $372,637, or 12 per cent. On the other hand we are compelled to note a decreased production of petroleum of 104,860 barrels, or 25 per cent.

		1909		1910		Increase (+) or decrease (—) in value.
		Quantity	Value	Quantity	Value	
			$		$	$
Copper	Lbs.	52,493,863	6,814,754	56,598,074	7,209,463	+ 394,709
Gold	Ozs.	453,865	9,382,230		10,224,910	+ 842,680
Pig Iron	Tons.	757,162	9,581,864	800,797	11,245,630	+ 1,663,766
Lead	Lbs.	45,857,424	1,692,139	32,987,508	1,237,032	— 455,107
Nickel	Lbs.	26,282,991	9,461,877	37,271,033	11,181,310	+ 1,719,433
Silver	Ozs.	27,529,473	14,178,504	31,983,328	17,106,604	+ 2,928,100
Other metallic products			405,122		559,186	+ 154,064
Total			51,516,490		58,764,135	+ 7,247,645
Less pig iron credited to imported ores		607,718	7,359,649	695,891	9,594,309	+ 2,234,660
Total metallic			44,156,841		49,169,826	+ 5,012,985
Asbestos and asbestic	Tons.	87,300	2,201,775	100,385	2,476,558	+ 274,783
Coal	"	10,501,475	24,781,236	12,796,512	29,811,750	+ 5,030,514
Gypsum	"	439,129	809,632	531,313	939,838	+ 130,206
Natural gas			1,207,029		1,312,614	+ 105,585
Petroleum	Brls.	420,755	559,604	315,895	388,550	— 171,054
Salt	Tons.	84,037	415,219	84,029	409,624	— 5,595
Cement	Brls.	4,067,709	5,345,802	4,753,975	6,414,315	+ 1,068,513
Clay products			6,450,810		7,600,000	+ 1,149,190
Lime	Bush.	5,592,924	1,132,756	5,721,285	1,131,407	+ 1,349
Stone			3,127,135		3,499,772	+ 372,637
Miscellaneous non-metallic			1,642,602		1,886,704	+ 244,102
Total non-metallic			47,674,600		55,871,132	+ 8,196,532
Grand total			91,831,441		105,040,958	+ 13,209,517

The subdivision of the mineral production in 1909 and 1910 by provinces was approximately as follows:—

Province	1909		1910	
	Value	Per cent. of total	Value	Per cent. of total
	$		$	
Nova Scotia	12,504,810	13.62	14,054,534	13.38
New Brunswick	657,035	0.71	585,891	0.56
Quebec	7,086,265	7.72	8,193,275	7.80
Ontario	37,374,577	40.70	43,017,026	40.95
Manitoba	1,193,377	1.30	1,470,776	1.40
Saskatchewan	456,246	0.50	557,806	0.53
Alberta	6,047,447	6.58	7,876,458	7.50
British Columbia	22,479,006	24.48	24,547,817	23.37
Yukon	4,032,678	4.39	4,737,375	4.51
	91,831,441	100.00	105,040,958	100.00

"It will be observed that there has been an increased production in nearly every province, the only falling off being shown by New Brunswick, in which the gypsum production, and some of the structural products, showed a slight decrease.

"In Nova Scotia there was a largely increased production of coal and gypsum. In Quebec the principal increases were in cement and asbestos. Ontario's increases are principally in the metals copper, nickel and silver.

"Manitoba shows an increased production of gypsum and clay products; while in Alberta clay products, cement, and particularly coal, contribute the chief gains. In British Columbia the increase is mainly due to the coal industry, while the Yukon not only shows a gratifying gain in gold production but a growing shipment of copper and silver ores.

"Of the total production in 1910, $49,169,826, or 46.8 per cent. is credited to the metals, and $55,871,132, or 53.2 per cent. to the non-metallic products. Amongst the individual products, coal still contributes the greatest value, constituting 28.4 per cent. of the total. Silver is next with about 16.3 per cent.; nickel third with 10.6 per cent.; gold, 9.7 per cent.; clay products, 7.2 per cent.; copper, 6.8 per cent., and cement, 6.1 per cent.

Product	Quantity	Value
METALLIC		$
Copper, value at 12.738 cents per pound .Lbs.	56,598,074	7,209,463
Gold	....	10,224,910
Pig iron and Canadian ore .... Tons	104,906	1,651,321
Iron ore (exports .... "	114,449	324,186
Lead, value at 3.75 cents per pound ...... Lbs.	32,987,508	1,237,032
Nickel, value at 30 cents per pound .... "	37,271,033	11,181,310
Silver, value at 53.486 cents per oz. ...... Ozs.	31,983,328	17,106,604
Zinc ore and other products	....	235,000
Total	....	49,169,826
NON-METALLIC		
Arsenic, white .... Tons.	1,502	75,328
Asbestos .... "	75,678	2,458,929
Asbestic .... "	24,707	17,629
Coal .... "	12,796,512	29,811,750
Corundum .... "	1,870	198,680
Feldspar .... "	15,719	47,867
Fluorspar .... "	2	15
Graphite .... "	1,243	59,087
Grindstones .... "	3,847	43,936
Gypsum .... "	513,313	939,838
Magnesite (railway shipments) .... "	328	2,493
Mica .... "	....	143,409
Ochres .... "	4,813	33,185
Mineral water	....	175,173
Natural gas	....	1,312,614
Peat .... Tons	771	1,735
Petroleum, value at $1.23 per barrel ..... Brls.	315,895	388,550
Phosphate .... Tons	1,319	11,780
Pyrites .... "	55,925	192,263
Quartz .... "	88,205	91,951
Salt .... "	84,092	409,624
Talc .... "	7,112	22,308
Tripolite .... "	22	134
Total	....	36,438,278
STRUCTURAL MATERIALS AND CLAY PRODUCTS.		
Cement, Portland .... Brls.	4,753,975	6,414,315
Clay products—		
Brick	....	5,930,630
Sewer pipe, fireclay, drain tile, pottery, etc.	....	1,669,370
Lime .... Bush.	5,721,285	1,131,407
Sand and gravel (exports) .... Tons	624,824	407,974
Sand lime brick	....	360,894
Slate	....	18,492
Stone—		
Granite	....	634,783
Limestone	....	2,303,804
Marble	....	158,779
Sandstone	....	402,406
Total structural materials and clay products	....	19,432,854
All other non-metallic	....	36,438,278
Total value, metallic	....	49,169,826
Total value, 1910	....	105,040,958

"In valuing the metallic production, the same general practice has been followed as in past years, with one or two slight modifications. Instead of valuing lead at the New York price, the average price at Toronto has been used. This is somewhat lower than the New York price, but higher than that in London.

"Nickel has been valued at an average price of 30 cents per pound, although the minimum quotation for the metal in large lots was 40 cents. Considerable quantities of monel metal are now made, the production of which does not require the separation of the nickel metal, and the price of 30 cents is equivalent to valuing two-thirds of the production at 37½ cents, and one-third at 15 cents.

"Complete returns of smelter production during 1910 have not yet been received; but the quantities of ore charged to the furnaces or smelter during each of the past three years is shown as under:

	1908	1909	1910
Nickel-copper ores	360,180	462,336	628,947
Silver-cobalt-nickel-arsenic ores	7,182	8,384	9,466
Lead and other ores treated in lead furnaces	53,545	53,006	57,547
Copper-gold-silver ores	1,797,488	1,850,889	*2,000,000
Total	2,218,395	2,374,615	2,695,960

*Returns incomplete; but tonnage probably exceeded the figure given.

"*Gold.*—While statistics of gold production are as yet incomplete, a preliminary estimate shows a production of approximately $10,224,910, an increase of about 9 per cent. over the 1909 production. The production of the Yukon is valued at $4,550,000, the total exports on which royalty was paid during the calendar year according to the records of the Interior Department, being 275,472.51 ounces. The Yukon production in 1909 was $3,960,000, the exports being 239,766.35 ounces. The British Columbia production in 1909 was placer gold $477,000; bullion from free milling ores $329,655; smelter recoveries $4,367,924. In 1910 the placer production is estimated by the Provincial Mineralogist as $482,000. An estimate of free milling bullion shipments and smelter recoveries is made of $4,950,000, or a total production for the province of $5,432,000. The Nova Scotia production shows a falling off of about $20,000, while Ontario will probably show a slight increase on account of the gold recovered in development work at Porcupine, of which a record has not yet been received.

"*Silver.*—The silver production of Canada in 1909 showed an increase of 24.5 per cent. over that of 1908, following a series of large increases during the three preceding years. It is very satisfactory therefore to be able to report a further increase in 1910 of about 16 per cent. The total production last year, including that produced as bullion and the metal estimated as recovered from ores sent to smelters or otherwise treated, was approximately 31,983,328 ounces, as compared with a production of 27,529,473 ounces in 1909.

"The increase is again chiefly credited to Cobalt and adjacent mining districts of Ontario,

"There was a slight falling off in the silver production of British Columbia as a result of the decreased production from the silver-lead ores of the province.

"For the Province of Ontario, complete returns have been received from all the larger operators, while estimates based on railway shipments have been made for two or three of the smaller mines. The net production of recoverable silver is estimated at 29,375,000 ounces, that is after deducting 5 per cent. from the settlement assays of ores sent to smelters to allow for smelting losses. At the average price of silver for the year this has a value of $15,711,513.

"The production similarly estimated for 1909 was 24,822,099 ounces, thus showing an increase in 1910 of about 4,552,901 ounces, or over 18 per cent.

"The total shipments of ore and concentrates were about 34,580 tons, containing approximately 29,931,678 ounces of silver, in addition to which somewhat over 940,000 ounces were shipped as bullion. The average silver content of ore and concentrates shipped was thus about 865.57 ounces, or $462.96 per ton, as compared with an average of 840 ounces in 1909.

"The shipments during 1909 were 27,835 tons of ore, containing 22,349,717 ounces of silver, or an average of 803 ounces per ton; 3,059 tons of concentrates containing 3,627,819 ounces, or an average of 1,186 ounces per ton, and bullion containing 143,440 fine ounces.

"The exports of silver in ore, etc., as reported by the Customs Department were 30,699,770 ounces, valued at $15,649,537.

"The price of refined silver in New York varied between a minimum of 50½ cents per ounce on March 2nd and a maximum of 56¾ cents on October 19th, the average monthly price being 53.486, as compared with an average monthly price of 51.503 cents in 1909.

"*Copper.*—No refined copper is produced in Canada, but the copper ores are mostly reduced to a matte or blister copper carrying values in the precious metals. In Quebec where the copper is recovered subsequently to the extraction of the sulphur from pyritic ores, there was increased activity during the year. A small quantity of ore was exported from British Columbia coast mines and the Yukon to United States smelters for treatment. In Ontario, where the copper is chiefly recovered from the nickel-copper ores of the Sudbury district, there is a very large increase in production. In British Columbia the most important events during the year were the acquisition of a controlling interest in the Dominion Copper Company by the British Columbia Copper Company, with the subsequent re-opening of several of the properties, and the destruction by fire of part of the head works of the Granby Mines at Phœnix, B.C., which noticeably affected the output, although the Boundary district as a whole shows an increased production.

"Statistics are not available at the present time to show the total quantity of copper contained in ores shipped from the mines. The total production of copper, however, contained in blister and matte produced and estimated as recoverable from ores exported was in 1910 approximately 56,598,074 pounds. In 1909 the production of copper estimated on the same basis was 52,493,863 pounds, an increased production of about 7.8 per cent., being therefore shown in 1910.

"Of the production in 1910, Quebec is credited with 957,178 pounds; the production in Ontario was 19,259,016 pounds; and in British Columbia the production is estimated at about 36,000,000 pounds. Ontario shows an increased production of about 3,512,317 pounds, or 22.3 per cent., while British Columbia shows a slight increase, the production in 1909 being estimated at 35,658,952 pounds.

"The New York price of electrolytic copper during the year varied between the limits of 12 cents and 13¾ cents per pound, the average being 12.738, as compared with an average of 12.982 cents in 1909.

"The total exports of copper contained in ore, matte and blister according to Customs Department returns were 56,964,127 pounds, valued at $5,840,553. It will be noted that the exports agree very closely in number of pounds with the record of the production, which would be expected since practically all the copper is exported.

"*Lead.*—The total production in 1910 of pig and manufactured lead was 32,987,508 pounds, valued at the average price of refined lead in Toronto at $1,237,032.

"The production of refined lead and lead contained in base bullion exported in 1909 was 45,857,424 pounds. A decreased production in 1910 is therefore shown of 12,869,916 pounds.

"The production of both years was entirely from British Columbia. The falling off in the output of that province is due largely to the curtailment of production by several of the important Slocan mines, consequent to the destruction of railway facilities and of several mines buildings by forest fires.

"The Blue Bell Mine also, one of the leading shippers of lead in 1909, suspended operations early in 1910. Against these decreases may be placed the advent of the Sullivan mine, East Kootenay, into the list of shippers.

"The exports of lead in ore during the year were 23 tons, and of pig lead 3,856 tons, or a total of 3,879.

"About 12,614 tons of domestic production were, therefore, available for home consumption.

"The imports of lead in 1910 were 8,305 tons, valued at $525,265, in addition to which were manufactures valued at $107,-688, and litharge, white and red lead, etc., $200,790, or a total value of $833,743.

"The price of lead in Toronto during 1910 averaged about 3.750 cents per pound, in New York 4.446 cents per pound and in London £12.920 per long ton.

"The amount of bounty paid during the twelve months ending December 31, 1910, on account of lead production was $318,-308.28, as compared with a payment of $346,527.98 in 1909.

"*Nickel.*—There has been a very large increase in the production of nickel-copper ores in Ontario during the past two years, and it is perhaps not generally realized that the production of nickel in this province is now almost as large, pound for pound, as the production of copper in British Columbia, while the market price of the metal is from two to three times that of copper. A portion of the production is, however, now recovered with copper as monel metal and sold at a much lower price than fine nickel. Active operations are being carried on by the same companies as formerly, viz.: the Mond Nickel Company, at Victoria Mines, and the Canadian Copper Company, at Copper Cliff.

"The ore is first roasted and then smelted and converted to a Bessemer matte containing from 77 to 82 per cent. of the combined metals, copper and nickel; the matte being shipped to the United States and Great Britain for refining.

"The total production of matte in 1910 was 35,033 tons, valued at the furnace at $5,380,064, an increase of 9,188 tons, or 31.6 per cent. over the production of 1909. The metallic contents were copper, 19,259,016 pounds, and nickel, 37,271,033 pounds.

"The aggregate results of the operations on the Sudbury District nickel-copper ores during the past four years were as follows in tons of 2,000 pounds:—

——	1907	1908	1909	1910
Ore mined	351,916	409,551	451,892	652,392
Ore smelted	359,076	360,180	462,336	628,947
Bessemer matte produced	22,041	21,197	25,845	35,033
Bessemer matte shipped	22,025	21,210	....	....
Copper contents of matte shipped	6,996	7,503	7,873	9,630
Nickel contents of matte shipped	10,595	9,572	13,141	18,625
Spot value of matte shipped	$3,289,382	$2,930,989	$3,913,017	$5,380,064
Wages paid	$1,278,694	$1,286,265	$1,234,904	$1,748,153
Men employed	1,660	1,690	1,735	....

"Exports of nickel contained in ore, matte, &c., as compiled from Customs reports have been, for the twelve months ending December 31, as follows:—

——	1906	1907	1908	1909	1910
	Pounds	Pounds	Pounds	Pounds	Pounds
To Great Britain	2,716,892	2,518,338	2,554,486	3,843,763	5,335,331
To United States.	17,936,953	16,857,997	16,865,407	21,772,635	30,679,451
	20,653,845	19,376,335	19,419,893	25,616,398	36,014,782

"The price of refined nickel in New York remained practically constant throughout the year—the quotation being "large lots, contract business, 40 to 45 cents per pound. Retail spot from 50 cents for 500 pound lots up to 55 cents for 200 pound lots. The price for electrolytic is 5 cents higher."

Iron.

"*Iron Ore.*—Excluding Quebec, for which complete returns have not been received, the production of iron ore in 1910 was 254,915 short tons, valued at $566,109. The shipments may be classified as magnetite, 124,535 tons, hematite, 130,380 tons. In 1909 the total shipments were 268,043 tons, valued at $659,316, and comprised magnetite, 74,240 tons, hematite, 190,473 tons, and bog ore, 3,330 tons.

"Exports of iron ore from Canada during 1910 are recorded by the Customs Department as 114,499 tons, valued at $324,186. This is chiefly from Moose Mountain mine, Ontario, Torbrook, N.S., and Bathurst, N.B.

"Although not a Canadian production, it may be of interest to state that the two Canadian companies operating the Wabana mines, shipped during the year 1,259,626 short tons of which 808,762 tons were shipped to Sydney and 450,864 tons to the United States and Europe.

"*Pig Iron.*—An increase of 5.58 per cent. is shown in the production of pig iron in Canada in 1910 as compared with 1909. The total production in 1910 was 800,797 short tons, valued at

$11,245,630, as compared with 757,162 tons, valued at $9,581,864 in 1909. These figures do not include the output from electric furnaces making ferro-products, which are situated at Welland and Sault Ste. Marie, Ont., and Buckingham, Que. Of the total output of pig iron during 1910, 17,164 tons valued at $333,956, or $19.78 per short ton were made with charcoal as fuel, and 783,633 tons valued at $10,911,674, or $13,92 per ton with coke. The amount of charcoal iron made in 1909 was 17,003 tons, and iron made with coke was 740,159 tons. The classification of the production of 1910, according to the purpose for which it was intended was as follows:—Bessemer 219,492 tons, basic, 425,400 tons, foundry, including miscellaneous, 138,741 tons.

"The amount of Canadian ore used during 1910 was 160,290 tons; imported ore 1,406,668 tons; mill cinder, &c., 22,671 tons.

"The amount of coke used during the year was 993,037 tons, comprising 499,717 tons from Canadian coal and 493,320 tons imported coke or coke made from imported coal.

"The consumption of charcoal was 1,615,919 bushels.

"Limestone flux was used to the extent of 569,355 tons.

"In connection with blast furnace operations there were employed, 1,403 men and $1,006,727 was paid in wages.

"The total daily capacity of 16 completed furnaces was, according to returns received, 2,880 tons.

"The number of furnaces in blast December 31, 1910, was 11.

"The production of pig iron by provinces in 1909 and 1910 was as follows:—

Province	1909			1910		
	Tons	Value	Per ton	Tons	Value	Per ton
		$	$ cts.		$	$ cts.
Nova Scotia. .	345,380	3,453,800	10 00	300,287	4,203,444	12 00
Quebec.	4,770	125,623	26 34	3,237	85,256	26 34
Ontario.	407,012	6,002,441	14 75	447,296	6,956,930	15 55
Total. . .	757,162	9,581,864	12 65	800,797	11,245,630	14 04

"The exports of pig iron during the year are reported as 9,763 tons, valued at $296,310. Probably the greater part of this is ferro-silicon and ferro-phosphorus, produced at Welland and Buckingham, respectively.

"There were imported during the year 227,753 tons of pig iron, valued at $3,122,695; 16,106 tons of charcoal pig valued at $242,152, and 18,900 tons of ferro-manganese, valued at $464,741.

"*Steel.*—The total production of ingots and castings in 1910 was approximately 822,281 short tons, of which 803,600 tons were ingots, and 18,681 tons were castings. The figures have been partially estimated, the records of the Ontario Iron and Steel Company having been unfortunately destroyed by fire. The production in 1909 was reported as 754,719 short tons, made up of 739,703 tons of ingots and 15,016 tons of castings.

"Returns from seven of the principal rolling mills report the production in 1910 of steel in the following shapes: blooms and billets 635,500 short tons; rails 399,761 tons; rods and bars 214,233 tons; miscellaneous rolled products, 23,167 tons.

"Statistics showing the open hearth and Bessemer steel production for four years are as follows:—

——	1907	1908	1909	1910
	Tons	Tons	Tons	Tons
Ingots—Open hearth (basic) .	459,240	443,442	535,988	580,932
Bessemer (acid).	225,989	135,557	203,715	22,668
Castings—Open hearth	20,602	9,051	14,013	18,083
Other steels.	1,151	713	1,003	598
Total.	706,982	588,763	754,719	822,281

"*Iron and Steel Bounties.*—Following is a statement of the bounties paid on iron and steel during the calendar years 1909 and 1910 as kindly furnished by the Trade and Commerce Department. As no bounty is paid on iron made from mill cinder or ingredients other than ore, the figures do not show the total output of the furnaces but only those quantities on which bounty was paid.

	1909		1910	
	Quantity on which Bounty was paid	Bounty	Quantity on which Bounty was paid	Bounty
	Tons	$ cts.	Tons	$ cts.
Pig iron made from Canadian ore...	126,297.55	214,705 80	84,758.70	76,282 83
Pig iron made from imported ore...	605,718.09	425,402 64	695,891.23	278,356 52
Total pig iron..	734,015.64	640,108 44	780,649.93	354,639 35
Steel ingots........	729,189.37	766,470 41	767,379 39	460,427 64
Steel wire rods.....	81,405.42	488,432 70	88,179.58	529,077 60
Total bounty paid on iron and steel	....	1,895,011 55	....	1,344,144 59

"*Zinc.*—The total zinc ore shipments in 1910 are reported as 5,063 tons, of which 4,487 tons were from British Columbia, and 576 from Ontario. The total zinc contents of ore shipment is reported as 4,361,712 pounds (2,181 tons).

"The value of the ore shipment was approximately $120,000.

"The imports of these ores into the United States from Canada as published in a recent pamphlet of the United States Geological Survey, were for the calendar year 1910, 4,749 tons (2,000 lbs.) containing 1,922 tons of metallic zinc. Similar imports during 1909 were reported as 10,024 tons, and during 1908, 7,406 tons.

"The shipments of zinc ore from mines in Canada in 1909, including British Columbia shipments for 1908, were reported as 18,371 tons containing approximately 8,234 tons of metallic zinc.

"*Asbestos.*—The total shipments of asbestos in 1910 with one firm still to hear from, are reported as 75,678 tons, valued at $2,458,929, as compared with 63,349 tons, valued at $2,284,587 in 1909, an increase of about 19 per cent. in tonnage and 7.6 per cent. in total value.

"The number of men employed in mines and mills is reported as 3,443, at a wage cost of $1,393,856. While the shipments are reported as above, the actual production was returned as 4,815 tons of crude and 91,353 tons of mill stock produced from 1,474,527 tons of asbestos rock, or a total production of 96,168 tons; stock on hand at the end of the year totalled 39,310 tons, as compared with 20,921 tons on hand at December 31, 1909.

"The following tabulated statement shows the production and shipments during 1910 and the stock on hand at the end of the year:—

—	Production	Shipments			Stock on hand Dec. 31	
	Tons	Tons	Value	Per ton	Tons	Value
			$	$		$
Crude No. 1..	1,971	1,688	445,130	263.70	1,605	426,782
" 2..	2,844	1,732	171,684	99.12	2,842	405,419
Mill Stock No. 1........	16,026	12,830	701,681	54.69	69,933	718,765
Mill Stock No. 2........	56,321	42,612	997,987	23.42	24,541	591,752
Mill Stock No. 3........	19,006	16,816	142,447	8.47	3,389	29,988
Total asbestos.	96,168	75,678	2,458,929	32.49	39,310	2,172,706
Asbestic.	....	24,707	17,629	0.71	....	

"In the absence of a uniform classification of asbestos of different grades, the above subdivisions have been adopted purely on a valuation basis. Crude No. 1 comprising material valued at $200 and upwards and Crude No. 2 under $200. Mill Stock No. 1 includes stock valued at from $45 to $100; No. 2 from $20 to $40; No. 3 under $20.

"The shipments of asbestos in 1909 were in detail as follows:—

Crude No. 1, 912 tons, value $246,655, or $270.37 per ton;

Crude No. 2, 2,162 tons, value $328,855, or $152.11 per ton;

Mill stock No. 1, 14,776 tons, value $785,731, or $53.18 per ton;

Mill stock No. 2, 32,417 tons, value $800,728, or $24.70 per ton;

Mill stock No. 3, 13,082 tons, value $122,618, or $9.37 per ton;

Total, 63,349 tons, value $2,284,587, or $36.06 per ton; asbestic, 23,951 tons, value $17,188.

"The exports of asbestos during the twelve months ending December, 1910, are reported by the Customs Department as 71,485 tons, valued at $2,108,632, comprising 57,939 tons, valued at $1,505,477 to the United States; 6,700 tons, value $280,452 to Great Britain; 440 tons, value $15,925 to Germany; 2,187 tons, value $94,619 to France, and 1,242 tons value $43,948 to other countries.

"The imports of manufactures of asbestos during the same period are reported as valued at $230,489.

"*Corundum.*—There was an increased production of corundum in 1910. The quantity of corundum ore treated during the year was 37,183 tons, from which was produced 1,686 tons of grain corundum. The shipments were 106 tons sold in Canada and 1,774 tons sold in other countries, a total of 1,870 tons, valued at $198,680.

"*Coal and Coke.*—The total coal production in Canada in 1910, comprising sales and shipments, colliery consumption and coal used in making coke, is estimated at 12,796,512 short tons, valued at $29,811,750. This is an increase of 2,295,037 tons, or nearly 22 per cent. over the production of 1909, and is the largest production of coal yet recorded for Canada.

"There has been an increased production from practically all the larger collieries, while in the Province of Alberta many new mines are being opened up and developed. The largest increases have been in the west—Alberta showing an increase of nearly 42 per cent. and British Columbia over 27 per cent., while Nova Scotia shows an increase of a little over 13 per cent. The total production is almost equally divided this year between the eastern and western coal fields, while Alberta contributes about 22 per cent. of the whole as compared with 10 per cent. in 1905 and 5 per cent. in 1900.

"The production by provinces was approximately as follows, the figures for 1908 and 1909 being also given. With respect to Alberta, while the table below shows a production in 1910 of

2,824,929 tons, the Provincial Mine Inspector estimates the output at over 3,000,000 tons.

Province	1908		1909		1910	
	Tons	Value	Tons	Value	Tons	Value
		$		$		$
Nova Scotia......	6,652,539	13,364,476	5,652,089	11,354,643	6,407,091	12,871,388
British Columbia .	2,333,708	7,292,838	2,606,127	8,144,147	3,319,368	10,373,024
Alberta..........	1,685,661	4,127,311	1,994,741	4,838,109	2,824,929	6,161,055
Saskatchewan....	150,556	253,790	192,125	296,339	190,484	293,448
New Brunswick...	60,000	135,000	49,029	98,496	53,455	106,910
Yukon Territory..	3,847	21,158	7,364	49,502	1,185	5,925
Totals....	10,886,311	25,194,573	10,501,475	24,781,236	12,796,512	29,811,750

"The exports of coal are reported by the Customs Department as 2,377,049 tons, valued at $6,077,350, as compared with exports of 1,588,099 tons in 1909, valued at $4,456,342.

"Imports of coal during the year include bituminous 5,966,466 tons, valued at $11,919,341; slack, 1,365,281 tons, valued at $1,795,598, and anthracite 3,266,235 tons, valued at $14,735,062, or a total of 10,597,982 tons, valued at $28,450,001.

"There was a greater importation of each class of coal than in 1909, when the total imports were 9,872,724 tons.

"*Coke.*—The total production of oven coke in 1910 was about 897,273 short tons, as compared with a production of 862,011 tons in 1909. The total quantity of coal charged to ovens was 1,373,793 short tons. By provinces the production was: Nova Scotia, 507,996 tons; Ontario, 25,959 tons; Alberta, 121,578 tons, and British Columbia, 241,740 tons. The coke is all made from Canadian coal with the exception of that made by the Atikokan Iron Company at Port Arthur, Ontario. All of the coke produced was used in Canada with the exception of 50,922 tons sold for export to the United States, chiefly from Alberta. The quantity sold for export in 1909 was 77,407 tons.

"The quantity of coke imported during the calendar year was 367,088 tons, valued at $1,908,725, as compared with imports of 761,425 tons, valued at $1,508,627 in 1909.

"*Chromite.*—No returns of production of chromite have been received; but 619 tons are reported as having been shipped by rail from Coleraine and Black Lake. An export of 15 tons valued at $150 is also reported by the Customs Department.

"*Petroleum and Natural Gas.*—The production of crude petroleum shows another large falling off in 1910, the production being only 315,895 barrels, or 11,056,337 gallons, valued at $388,550, as compared with 420,755 barrels, or 14,726,433 gallons, valued at $559,604 in 1909. The average price per barrel was also less, being about $1.23 in 1910, as compared with $1.33 in 1909.

"The above statistics of production have been kindly furnished by the Trade and Commerce Department, and represent the quantities of oil on which bounty was paid, the total bounty payments being $165,845.06 in 1910 and $220,896.50 in 1909.

"The production in Ontario by districts as furnished by the Supervisor of Petroleum Bounties, was, in 1910, as follows, in barrels:—Lambton, 205,456; Tilbury and Romney, 63,058; Bothwell, 36,998: Leamington, 141; Dutton, 7,752, and Onondaga (Brant county) 1,005.

"The production in New Brunswick was 1,485 barrels.

"In 1909 the production by districts was as follows, in barrels: —Lambton, 243,123; Tilbury and Romney, 124,003; Bothwell, 38,092; Leamington, 5,929, and Dutton, 9,513. New Brunswick produced 95 barrels.

"While the production has been decreasing, the imports as might be expected have been increasing. The total imports of petroleum oils, crude and refined, in 1910 were 67,949,643 gallons, valued at $3,133,449, in addition to 1,362,235 pounds of wax and candles, valued at $80,106. The oil imports included, crude oil, 53,604,053 gallons; refined and illuminating oils, 7,656,727 gallons; lubricating oils, 3,071,257 gallons; other petroleum products, 2,607,606 gallons.

"The production of natural gas was valued at $1,312,614, being $68,568 for the Province of Alberta and $1,244,046 for Ontario. These values represent as closely as can be ascertained the value received by the owners of the wells for gas produced and sold or used and do not necessarily represent what the consumers have to pay for the gas, since in a number of instances the gas is re-sold once or twice by pipe line companies before reaching the consumer. In Alberta, also, some gas is being used by brick manufacturers for which no estimate has been obtained as to quantity or value. The total quantity of gas used in Ontario exceeded 7,036 million feet, and in Alberta over 450 million feet. A considerable flow of gas is reported from the new wells of the Maritime Oil Co., Ltd., in Albert county, New Brunswick, which it is proposed to pipe to Moncton.

"*Salt.*—Complete returns of salt production show total sales of 84,092 tons, valued at $409,624 for the salt alone. Packages used were valued at $173,446. Stock on hand at the end of the year was reported as 2,474 tons. Two hundred and eight men were employed and $112,909 paid in wages. The production was about the same as in 1909.

"Imports of salt during the calendar year were:—salt in bulk and bags dutiable, 20,174 tons, valued at $97,326, and salt free of duty 108,794 tons, valued at $364,735.

"*Cement.*—Complete statistics have been received from the manufacturers of cement, covering their production and shipments during the year 1910. These returns show that the total quantity of cement made during the year, including both Portland and slag cement, was 4,396,282 barrels, as compared with 4,146,708 barrels in 1909, an increase of 249,574 barrels, or 6 per cent.

"The total quantity of Canadian Portland cement sold during the year was 4,753,975 barrels as compared with 4,067,709 barrels in 1909, an increase of 686,266 barrels, or 16.87 per cent. The total consumption of Portland cement in 1910, including Canadian and imported cement, and neglecting an export of Canadian cement valued at $12,914, was 5,103,285 barrels, as compared with 4,209,903 barrels in 1909, or an increase of 893,382 barrels, or 21.22 per cent.

"Detailed statistics of production during the past four years are shown as follows:—

—	1907	1908	1909	1910
	Barrels	Barrels	Barrels	Barrels
Portland cement sold........	2,436,093	2,665,289	4,067,709	4,753,975
" manufactured..	2,491,513	3,495,961	4,146,708	4,396,282
Stock on hand January 1....	299,015	383,349	1,098,239	1,180,231
Stock on hand December 31..	354,435	1,214,021	1,177,238	822,538
Value of cement sold........	$3,777,328	$3,709,063	$5,345,802	$6,414,315
Wages paid................	$956,080	$1,275,638	$1,266,128	$1,323,264
Men employed.............	1,786	3,029	2,498	2,085

"The average price per barrel at the works in 1910 was $1.34; as compared with an average price of $1.31 reported for 1909, and $1.39 in 1908.

"The imports of Portland cement into Canada during the twelve months ending December 31, 1910, were 1,222,586 cwt., valued at $468,046. This is equivalent to 349,310 barrels of 350 pounds at an average price per barrel of $1.34. The imports in 1909 were 142,194 barrels, valued at $166,669, or an average price per barrel of $1.17.

"The imports from Great Britain during 1910 were 123,880 barrels, valued at $130,951; from the United States, 168,972 barrels, valued at $253,463; from Belgium 19,027 barrels, valued at $20,618; and from other countries 37,431 barrels, valued at $63,014.

"Following is an estimate of the Canadian consumption of Portland cement for the past six years:—

Calendar Years	Canadian		Imported		Total
	Barrels	Per cent.	Barrels	Per cent.	Barrels
1905........	1,346,548	59	918,701	41	2,285,249
1906........	2,119,764	76	665,845	24	2,785,609
1907........	2,436,093	78	672,630	22	3,108,723
1908........	2,665,289	85	469,049	15	3,134,338
1909........	4,067,709	97	142,194	3	4,209,903
1910........	4,753,975	93	349,310	7	5,103,285

Mr. HIRAM DONKIN, Deputy Commissioner of Public Works, of Nova Scotia, transmitted the following report, which was summarized by the Secretary:—

NOVA SCOTIA MINING INDUSTRY IN 1910.

"*Coal.*—The output was in round figures 5,477,000, an improvement on last year. The outlook for this year is encouraging as the labour difficulties at the colleries, with the exception of Springhill, have been overcome.

It is confidently expected the output for this year will be the largest in the history of the industry.

"*Gold.*—The production of 10,675 ounces from 59,058 tons of quartz crushed shows a slight decrease in comparison with the production of last year. The industry at the present time is about holding its own. Operations are being carried on in about fifteen of the gold districts of the Province and between 400 and 500 men are daily employed.

"*Iron.*—The only ore mined in the Province is that recovered at Torbrook by the Canada Iron Corporation. During the past two years extensive underground development work and surface construction work have been engaged in, and this company is now in a position to mine and ship greatly increased quantities of ore.

Extensive prospecting work was carried on at Arisaig, resulting in the opening up at a number of places of several veins of hematite ore.

"*Gypsum.*—The gypsum quarried and shipped from the Province during the year shows a substantial increase over the number of tons quarried and shipped during the previous year, and the future of this industry is very encouraging.

"*Tungsten.*—During the year 75 tons of Scheelite (ore of tungsten) were recovered by the Nova Scotia Tungsten Company from their property at Moose River, Halifax County. This ore was won from the development excavations. A number of shafts have been sunk on this property ranging in depth from 20 to 120 feet, and exploring some six scheelite-bearing veins. While sufficient work has not as yet been done to warrant definite conclusions as to the extent or value of the ore, enough has been done to show that the deposit is a most important one.

"*Other minerals.*—The antimony recovered was in the form of concentrates made by The West Gore Antimony Company from their dump accumulation. No ore has been mined during the year. Twenty-five tons of manganese ore was recovered by The New Ross Manganese Company at New Ross. This ore is of a particularly high grade, and in demand by glass manufacturers. The ore recovered came from prospect workings.

"The building stone quarried shows a large decrease in comparison with the previous year. This may be accounted for by the more general use of cement.

"The limestone quarried for fluxing purposes at the steel plants shows a substantial increase over the year 1909.

"The coke made shows a slight decrease.

"Generally speaking the mineral production of Nova Scotia during the past year shows a substantial increase over the production of the previous year and indications at the present time point to a further increase during the year 1911."

NEW BRUNSWICK MINERAL PRODUCTION 1910.

The following report of operations in this Province for the year 1910 was kindly supplied by the HON. W. C. H. GRIMMER, Surveyor General:

The mineral output of New Brunswick is confined practically to coal, gypsum and iron. Natural gas, also, if it may be called a product of the mine, together with a small quantity of mineral oil, is being produced in the County of Westmorland.

Coal has been mined to a certain extent for many years in what is called the Grand Lake region situate in the Counties of Queens and Sunbury. It is found in comparatively thin seams or beds not far from the surface of the ground and when properly mined furnishes a good quality of bituminous coal. During the fiscal year ending October 31st, 1910, there were mined and shipped by rail from this district 41,079 tons of coal. Of the coal shipped by water there is no record kept as on this there is no royalty imposed. During the same period 5993 tons of coal were mined in the vicinity of Beersville, County of Kent. These are the only localities in New Brunswick where coal is mined commercially.

One of the most stable of the mining industries of the Province is that of gypsum production, the bulk of which comes from the mines of the Albert Manufacturing Company of Hillsborough, although it has been mined to a certain extent at Plaster Rock on the Tobique. This Company employs an average of 350 men and boys throughout the year and during the last year quarried on four of their leases (Nos. 3, 4, 5 and 6) 93,499 tons of crude gypsum. Meanwhile, development work is proceeding on their other leased property. Most of their quarrying operations are in open cuts except in cases where there is a considerable depth of clay, when tunnelling is resorted to: but this is not done to any great extent. Their exports of crude gypsum (shipped just as quarried in lump form principally by steamers) will this year amount to between 55,000 and 60,000 tons; but a considerable portion of the product is reduced at the Hillsborough works and shipped in manufactured form to various points through Canada, also to the United States and even to Australia, shipments to the last being made direct by steamer from St. John and Montreal. The shipment of plaster this year to Canadian points will amount to about 110,000 barrels and to the United States about 18,000 barrels. A barrel usually contains 300 pounds; but in a few special shipments the weight is 250 pounds per barrel. The manufactured product is principally plaster of paris and hard wall plaster, although a certain amount is put up for land plaster or fertilizer.

For a year or more past the Drummond Mines, Ltd., have been preparing to develop their iron mines in the County of Gloucester. They built a branch line of railway 17 miles long to connect with the Intercolonial Railway near Gloucester Junction in order to afford facilities for shipping their product from the port of Newcastle. Previous to November 1st there had been mined 15,640 tons of ore of which 12,224 tons had been conveyed to the dock ready for transportation to the smelter. This Company has installed a modern drilling and crushing plant at their mines, with shops, compressor plant, ore pocket, locomotive shed station, and buildings for employees.

In April of the year 1909 the Maritime Oilfields, Limited, who had previously obtained rights under the lease to the New Brunswick Petroleum Company, commenced drilling for oil and natural gas at a point about 3 miles east of the City of Moncton. Nothing of value having been found after going to a depth of 1,220 feet, a new hole was started at a point 11 miles south east of Moncton. When a depth of 2,400 feet had been reached the drilling apparatus was destroyed by fire and although every effort was made to recover the drilling tools which had dropped to the bottom of the hole as a result of the fire, it was found impossible to do so and the hole was abandoned. Drilling was then, in the month of July, 1909, commenced at Stoney Creek about 10 miles south of Moncton; and between that time and the end of October, 1910, 15 holes having an average depth of 1,630 feet have been drilled. Of these one is not yet completed and three produced nothing; but from the remaining 11 there has been an abundant supply of natural gas averaging 3,173,000 cubic feet per day with a range from 20,000 cubic feet minimum to 10,000,000 cubic feet of a maximum discharge. The pressure of gas at the well's mouth runs from about 100 pounds per square inch up to 610 pounds per square inch. Oil said to be of excellent quality was found in these wells; but owing to the strong flow of gas it was not practicable to torpedo the oil sands and the output of oil is consequently small, being in all about 50,000 gallons to the end of October. The Company has provided a Power House and pumping plant and has erected six tanks having a total capacity of 1,450 gallons to provide for the oil that is produced. Their total expenditure to the 30th of September, 1910, amounts to $92,929 exclusive of $25,000 the purchase price of the plant, etc., taken over from the New Brunswick Petroleum Company.

QUEBEC MINERAL PRODUCTION, 1910.

MR. T. DENIS, Superintendent of Mines for the Province of Quebec, presented a statement of mineral production for the year 1910. The following are the returns as finally revised:—

		1910		1909
		Quantity	Value	Value
			$	$
1	Bog Iron Ore. . . . . .Tons	1207	4,406	4,668
2	Ochres. . . . . "	4812	33,185	28,093
3	Chromite. . . . . "	299	3,734	26,604
4	Copper and sulphur ore. . . . . "	24,052	145,165	215,580
5	Asbestos. . . . . "	80,605	2,667,829	2,296,584
6	Asbestic. . . . . "	24,716	17,612	20,468
7	Mica. . . . . .Lbs.	251,419	51,901	27,034
8	Phosphate. . . . . .Tons	. . . .	3,182	4,800
9	Graphite.	309,490	15,896	10,339
10	Mineral Waters. . . . . .Galls.	216,600	68,155	17,246
11	Titaniferous Iron ore. . . . . .Tons	3,568	5,292	
12	Slate. . . . . .Squares	3,959	18,492	24,000
13	Cement. . . . . .Bbls.	1,563,716	1,954,646	1,314,551
14	Magnesite. . . . . .Tons	322	2,160	2,508
15	Marble.	. . . .	151,103	130,000
16	Flagstone.	. . . .	890	8,500
17	Granite.	. . . .	291,240	149,064
18	Lime.	. . . .	279,306	105,488
19	Limestone.	. . . .	503,173	457,143
20	Bricks. . . . . .M	128,951	906,375	584,371
21	Sewer pipes, tiles and Pottery.	. . . .	197,526	125,000
22	Quartz. . . . . .Tons	805	2,013	
	Totals.		7,323,281	5,552,062

"The above table presents the figures of the mineral production of the Province of Quebec, as compiled from the returns received from the producers, for the year ending December 31st, 1910. The total will be seen to be $7,323,281, an increase of $1,771,319 over the total of the revised production for the preceding year 1909, which is given in the adjoining column.

"At first sight the increase may appear very large; but it must be said that to a certain extent it is more apparent than real, and is in a measure due to a more thorough collecting of data of such products as structural materials, mineral waters, etc. Nevertheless a comparison of the various individual items for 1910, with those for 1909, will show substantial increases in almost every case indicating on the whole a very gratifying state of the mineral industry in the Province.

"The following table gives the annual value of the mineral production of the Province for the last decade:

Year	Value
1901	$2,997,731
1902	2,985,463
1903	2,772,762
1904	3,023,568
1905	3,750,300
1906	5,019,932
1907	5,391,368
1908	5,458,998
1909	5,552,062
1910	7,323,281

"*Asbestos*—The asbestos and asbestic sold and shipped during the year amounted to 105,321 tons, representing a value of $2,685,441, as follows:—

	Tons	Value
Crude Asbestos		
No. 1, No. 2 and No. 3....	3,429	$ 668,031
Mill Stock..............	77,176	1,999,798
	80,605	2,667,829
Asbestic...............	24,711	17,612
	105,316	$2,685,441

This is a substantial increase over the preceding year, but is slightly below the value of the asbestos and asbestic produced in the banner year 1908, when it reached $2,577,302.

"The asbestos industry in 1910 was very active; much more so than the figures given above seem to indicate, for at the close of the year considerable stocks remained on hand. There was in fact, an over-production and the market could not absorb all the output of the mills. From this cause the asbestos industry is at present undergoing a slight crisis; but everything points to this as being only a temporary embarrassment, and there is no doubt that within a short time there will be a re-adjustment between consumption and production.

"The mines themselves and the mills are in excellent condition. At the depths reached, over 200 feet in some cases, there is no apparent decrease in the contents of asbestos of the rock.

"*Iron*—The returns received from pig iron producers give a quantity of 1,207 tons of bog iron ore, to which they assign a much higher value per ton than in past years. This is perhaps due to the fact that formerly the iron producers worked some iron deposits themselves, and their returns properly gave the actual cost of mining. Whereas at present the bog iron ore used in the furnaces is obtained from numerous small producers, and the price assigned to the ore represents its value delivered at the furnace.

"We do not include in the total production, the value of the pig iron made. There was in 1910 a quantity of 2,890 tons, valued at $91,000. This is high grade wood-charcoal pig iron, which brings a high price in the market.

"The titaniferous iron ore was mined from the St. Urbain deposits. Part of it was used in the manufacture of steel, and the rest in the manufacture of a certain grade of electrodes. All was exported.

"*Mica and Phosphate.*—Substantial increases in sales and output are shown in these products. A large proportion of these were made from stocks carried over from the previous year, and the actual mining of these substances was not very active throughout the year. The market is, however, markedly improving and everything points to greater activity during the coming year. The greater part of the phosphate was used in the manufacture of phosphorus.

"*Copper and Iron Pyrites.*—The largest producer is still the Eustis Mining Company; but a new mine operated by the Eastern Canada Smelter Company at Weedon, has also made substantial shipments.

"*Cement.*—The products of this industry in the Province show an increase in value of $640,095, which is a proportionate increase of 48% over the value of the production of the preceding year. Such increases are significant and indicate the preponderating part which cement is taking among the building materials. It is sufficient to recall that in 1904 the total production of cement in the Province was slightly over $50,000, while two years later it was $625,000. It is now nearly $2,000,000.

5

"All of the other building materials show very large increases as compared with the previous years. Part of these increases, as was mentioned before, is undoubtedly due to a more thorough collecting of figures; but, nevertheless, there has been a much greater building activity throughout the Province than ever before.

ONTARIO MINERAL RETURNS.

Mr. THOMAS W. GIBSON, Deputy Minister of Mines of Ontario, in submitting the returns of that Province for the past year said:—

"As I have remarked on previous occasions it is highly desirable that an agreement should be reached between the Dominion Department of Mines and those of the several Provinces for the standardization of methods for computing mineral statistics and returns with a view to uniformity of presentment. The present diversity of methods is disconcerting to the inquirer desiring information for comparative purposes.

"Thus the basis adopted by the Ontario Bureau in compiling statistics is the value of the several products in the form produced, and at the point of production. Hence, nickel and copper are appraised as constituents of matte at the smelting works of Sudbury. Were the values of nickel and copper taken at the price of the refined metals, in conformity, for example, with the methods of the Dominion and British Columbia Departments of Mines, and the total output of silver computed at the average price for the year in New York, the value of the mineral production of Ontario would appear to be some fourteen millions of dollars above the present returns, or a total of over forty-two and a-half million dollars,—more than 40 per cent. of the total value of the mineral production of the whole of Canada for the year 1910.

"The returns for the year are as follows:—

MINERAL PRODUCTION OF ONTARIO, 1910.

Product		Quantity	Value
METALLIC.			$
Gold	oz.	3,619	68,498
Silver	"	30,651,417	15,481,322
Cobalt	Tons	1,098	54,699
Nickel	"	19,140	4,005,961
Copper	"	9,630	1,374,103
Iron Ore	"	230,656	513,721
Pig Iron	"	447,351	6,975,418
Zinc Ore	"	576	5,760
			28,479,482
Less Ontario iron ore (143,284 tons) smelted into pig iron			317,804
Net metallic production		....	28,161,678
NON-METALLIC.			
Actinolite	Tons	32	320
Arsenic (refined)	"	1,524	70,709
Arsenic (crude)	"	3,373	....
Brick, common	No.	304,988,000	2,374,287
Tile, drain	"	21,028,000	318,456
Brick, pressed	"	44,204,295	458,596
Brick, paving	"	3,799,025	70,648
Building and crushed stone		....	761,126
Calcium carbide	Tons	3,072	184,323
Cement, Portland	Bbls.	2,471,837	3,144,343
Corundum	Tons	1,870	171,994
Feldspar	"	16,374	47,518
Fluorspar	"	2	15
Graphite	"	992	55,637
Gypsum	"	10,043	17,825
Iron Pyrites	"	33,812	98,353
Lime	Bush.	2,889,235	474,531
Mica	Tons	513	85,294
Natural gas		....	1,491,239
Peat	Tons	851	1,284
Petroleum	Imp. gal.	11,004,357	368,153
Pottery		....	51,485
Quartz	Tons	90,685	87,424
Salt	"	84,071	414,978
Sewer pipe		....	357,087
Talc	Tons	5,824	46,592
			11,152,217
Add metallic production			28,161,678
Total production			39,313,895

"*Gold.*—The production, $68,498 is double in value that of 1909. More than half the yield came from the new camp at Porcupine, where active developments are in progress, and where large stamp mills are being erected at the Hollinger and Dome mines. A branch of the Temiskaming and Northern Ontario Railway—the Ontario Government line—is being built into Porcupine from the main line at Mileage 224, near Kelso. At Long lake, on the Sault branch of the Canadian Pacific Railway, gold is being obtained by the Canadian Exploration Company from an arsenical ore. The old Mikado mine at Shoal lake, Lake of the Woods, and the Havilah, formerly the Ophir, in the township of Galbraith, have been re-opened. In Hastings county the Cordova or Belmont mine, long idle, has recently changed hands, and it is understood will soon be again operated.

"*Silver.*—The entire production, with a trifling exception, comes from the mines of Cobalt, including in that term not only Cobalt proper, but Gowganda and South Lorrain. Shipments comprised 27,485 tons of ore and 6,874 tons of concentrates, in all 34,359 tons, bringing the total shipments from the camp since the beginning up to 113,008 tons, of which 10,930 tons were concentrates. The total silver contents of the shipments for 1910 were 30,651,417 ounces, or an average of 863·5 ounces per ton, taking ore and concentrates together. For the whole period since the mines were opened Cobalt has produced 94,064,189 ounces of silver, which brought the mine-owners the sum of $48,368,333. The average tenor of the shipments fell from 1,309 ounces per ton in 1904 to 677 ounces per ton in 1907, in which year low-grade ores began to be shipped in considerable quantity, before concentration plants were introduced. In 1908 the effect of concentration now a well-developed feature of the camp, began to be noticeable, and the average contents per ton rose to 758 ounces, in 1909 to 844 ounces, and in 1910 to 863·5 ounces. The improvement would have been still greater were it not for the large quantities of low-grade ore or rock which have been shipped to Denver and other smelting points for use largely as flux, much of it containing less than 60 ounces silver per ton.

"The extension of concentration processes—there being now 14 concentrating mills at work—the shipment of bar silver from several properties, and the introduction and universal adoption of hydraulically developed electrical power, were noticeable features of the Cobalt camp in 1910. The power transmitted from the falls on the Montreal and Matabitchewan rivers has materially reduced the cost of operations, the price being lowered from about $150 per horse power when using steam to $50.

"The principal producers at Cobalt were Nipissing, which led with a production of 5,590,080 ounces, La Rose 3,484,754 ounces, Crown Reserve 3,255,567 ounces, Kerr Lake 2,877,299 ounces, Coniagas 2,621,681 ounces, McKinley-Darragh-Savage 2,606,891 ounces, Temiskaming 1,994,226 ounces and Buffalo 1,629,328 ounces; others with large outputs were O'Brien, Hudson Bay, Trethewey, Right of Way, etc.

"In the newer fields of Gowganda and South Lorrain, six mines in the former shipped 480 tons of ore, containing 481,523 ounces of silver, and two in the latter 233 tons, containing 221,233 ounces.

"Much the greater proportion of the high-grade ore from Cobalt is now treated by refineries in Ontario. These are three in number, at Copper Cliff, Deloro and Thorold. All produce merchantable bars for the London market. The quantity of silver recovered at these plants during the year was 14,574,837 ounces.

"It may be pointed out that Ontario now ranks third among the silver-producing communities of the world, being surpassed only by Mexico and the United States. In 1910 her output was only one and a half million ounces short of the combined production of Montana, Utah and Nevada, the three largest silver States of the Union.

"That silver-mining at Cobalt as a whole is a profitable undertaking may be deduced from the fact that the dividends declared in 1910 amounted to $7,275,240, or nearly one-half the total returns from the silver produced. Up to the end of the year the total dividends distributed amounted to $21,802,180, not including the profits made by two or three mines, either individually owned or close corporations.

"*Cobalt.*– The quantity of cobalt shown in the table is only that part of the output for which the mining companies were paid by purchasers of ore. A much larger quantity was shipped out, but for the most part brought no returns. No assays of it are made or records kept, consequently no exact data are available. The price of cobalt oxide has fallen to 75 or 80 cents per pound, and further reductions seem inevitable, if the law of supply and demand is allowed to have its natural effect.

"*Nickel.*—The nickel-copper mines of the Sudbury region, now the most important source of nickel not only in America but in the world, were operated vigorously in 1910, and the output of nickel—18,636 tons—exceeds that of 1909, previously the largest on record, by 5,495 tons. The matte product of the Bessemer furnaces was 35,033 tons, and the value of the nickel contents was returned at $4,005,961, or 10.7 cents per pound. Valued at 40 cents, the price quoted for refined nickel in New York, the output of nickel was worth $14,908,800, but credit it taken herein at the smaller figure only, which represents, or is supposed to represent, the value of the nickel in the matte, when it leaves the smelters for the United States or Wales, where the final separation and refinement take place.

"There are two companies mining and producing nickel, the Canadian Copper Company, whose works are at Copper Cliff, and the Mond Nickel Company at Victoria Mines. Both operate well-equipped plants, first smelting the ore and then converting it into a Bessemer matte containing approximately 80 per cent. of nickel and copper. The Canadian Copper Company draws its supplies of ore principally from the Creighton and Crean Hill mines, the former being richer in nickel than in copper, and the latter *vice versa.* Hitherto the Victoria Mines have been the chief sources of supply for the Mond Company, but latterly the Garson mine has been largely drawn upon, and the company has under consideration the removal of its furnaces to a point east of Sudbury and nearer the Garson ore body. Both companies operate their mines and works by electrical power, the Copper Company utilizing falls on the Spanish river, and the Mond Company falls on the Vermilion. The Dominion Nickel-Copper Company, formed to work large deposits of ore on the northern range, has not yet reached the stage of production.

"The nickel contents of the silver-cobalt ores, which yield nothing to the mine owners, bring the total output of nickel up to 19,140 tons.

"*Copper.*—Most of the copper produced in Ontario is found accompanying the nickel in the ores of Sudbury, consequently the yield rises or falls with that of the principal metal. The copper contents of the matte produced in 1910 amounted to 9,630 tons, valued at $1,374,103, or at the rate of 7.1 cents per pound. If reckoned at the average value of electrolytic copper in New York for 1910, viz.: 12.73 cents per pound, the value would be $2,451,-798. A small part of the copper is to be credited to Bruce Mines, from which a quantity of silicious ore was shipped to Victoria Mines and used for converter linings.

"*Iron Ore and Pig Iron.*—Four iron mines were in operation in 1910, producing 230,656 tons of ore, which is a falling-off as compared with 1909, when the output was 263,777 tons. Of the ore 119,207 tons was magnetite from Moose Mountain, Atik-okan and Bessemer; 112,246 tons was hematite from Helen mine. The ore was returned as worth $513,721, or $2.22 per ton. The Lake Superior Corporation have been developing an iron prospect called the Magpie mine in Michipicoten district, and have ascertained by borings that it contains a large body. The ore is sideritic; but preliminary roasting will reduce the sulphur contents and raise the percentage of metallic iron. At Moose Mountain it is proposed to increase the facilities for concentrating the ore.

"There were eight blast furnaces at work producing pig iron last year, the total yield being 447,351 tons. The total quantity of ore charged into the furnaces was 822,174 tons, of which 143,284 tons was of domestic and 678,890 tons of foreign origin. The value of the pig product was $6,975,418. Steel produced amounted to 331,321 tons, valued at $7,855,407.

NON-METALS.

"*Building materials.*—The raw materials for building purposes are plentiful in Ontario, including clay for making brick, etc., limestone for lime and construction work, sandstone and granite, Portland cement, etc. Building operations were brisk and called for an increased production of brick and lime as compared with 1909. The Portland cement industry is steadily growing, the production being 2,471,837 bbls. as compared with 2,303,263 bbls. in 1909. The aggregate value of products which may be classed as construction materials, including brick and other clay products, stone, Portland cement and lime, was $7,959,-

074. Part of the stone, however, was for use as flux in blast furnaces and road-making.

"*Petroleum.*—Of late years the production of petroleum has been declining. In 1910 the yield amounted to only 11,004,357 Imperial gallons, which is about one-third the production of 20 years ago. The diminution is most marked in the newer field of Tilbury, but is also going on in the older districts of Petrolea and Oil Springs. The average production per well is now very small, averaging only a few gallons daily. A new oil pool was located during the year in Onondaga township, but the production has not yet been important.

"*Natural Gas.*—On the other hand, the flow of natural gas is increasing year by year, in 1910 amounting in value to $1,491,239, at a low rate per thousand cubic feet, as compared with $1,188,179 in 1909. The gas fields are confined to the Lake Erie counties, but the gas finds a ready market not only in the localities in which it is produced, but also in the cities, towns and villages of south-western Ontario. Several wells have been drilled in the shallow water along the shore of the lake, and a new field is being exploited in the township of Bayham, Elgin County.

"*Minor Products.*—The list of Ontario minerals is long and varied, and a number of other substances in the table of production constitute the basis of industries of considerable importance. Among these are salt, corundum, iron pyrites, feldspar, quartz, graphite, talc, gypsum, arsenic, etc. It is not, however, necessary in a summary statement of this kind to refer to these at length."

Mr. GIBSON added: "I would direct attention in particular to the decrease in petroleum output. If this continues, and in the absence of the development of new fields, we shall soon be within measurable distance of the suspension of oil production in Ontario. As to natural gas it is my opinion that its use for industrial purposes should be discontinued and that instead it be utilized exclusively for domestic purposes. It is an admirable domestic fuel."

SASKATCHEWAN.

The following returns of coal production for the year ending Feb. 28th, 1910 are kindly supplied by the Coal Mines Branch, Department of Public Works, Regina:

Number of Mines in operation February 1910.	30
Number of tons produced in 12 months	208,902
Number of persons employed, inside mines	287
Number of persons employed, outside mines	89
Number of accidents, fatal	1
Number of accidents (reported) non-fatal	5

COAL PRODUCTION, ALBERTA, 1910.

The following returns were kindly furnished by Mr. John F. Sterling, Provincial Inspector of Mines:—

"The total output of coal from the Province of Alberta for the year 1910 was approximately 3,020,000 tons.

The following table indicates how the Bituminous Coal and Coke outputs of the Province were disposed of:—

Tons of 2,000 lbs.	Crow's Nest Pass District		Calgary District	
	Coal	Coke	Coal	Coke
Sold for consumption in Alberta. ...	1,017.969	136	273.752	
Sold for consumption in other provinces.	124.274	70.297	....	
Sold for export to the United States..	215.976	51.144	....	
Total sales.	1,358.219	121.575	273.752	
Used in making Coke.	196.249	....	....	
Used under Colliery Boilers........	53.737	....	9.940	
Total for Colliery use.	249.986	....	9.940	

The following table indicates how the Anthracite Coal and Briquette outputs of the Province were disposed of—

Tons of 2,000 lbs.	Calgary District	
	Coal	Briquettes
Sold for consumption in Alberta.	40.091	89,383
Sold for consumption in other provinces.	43,110	19,387
Sold for export to the United States.	758	44
Total sales.	83,959	108,814
Used under Colliery Boilers.......................	38,848	182

	Tons
Output of Bituminous Coal (total for Province)	1,896,757
Output of Anthracite Coal (total for Province)	261,785
Output of Lignite Coal (total for Province) (approx.)	861,458
Approx. total	3,020,000

MINERAL PRODUCTION OF BRITISH COLUMBIA, 1910.*

It is of interest to note that this Province continues to maintain its average proportion of the mineral production of that of the whole of Canada. Placing the aggregate value of the production of the Dominion for the twenty-five years 1886–1910, included in the published official records, at $1,120,000,000 (which allows about $95,000,000 for 1910), it would appear that British Columbia may fairly claim to have produced between 27 and 28 per cent. of this large sum. The aggregate value of the mineral production of this Province for all years to 1910, inclusive, is nearly $374,000,000. Deducting the total value of the minerals—chiefly for coal and placer gold—produced prior to 1886, which was nearly $64,000,000, British Columbia's approximate aggregate for the twenty-five years is left at $310,000,000, which is between 27 and 28 per cent. of that of the whole of Canada. It is a striking fact, as indicating the substantial increase in the value of the mineral production of the Province in recent years as compared with that prior to 1906, that fully 40 per cent, of this large value is the production of the last five years, 1906–1910, while more than half—53.7 per cent.—is that of seven years, 1904–1910.

The following table shows in detail the quantities and the value of the various mineral products for the years 1909 and 1910. The returns in respect of building-stone, lime, bricks, tiles, etc., are an estimation:—

* Compiled from "a Preliminary Review and Estimate of Mineral Production for the year 1910," by W. Fleet Robertson, Provincial Mineralogist and Report of the Minister of Mines (British Columbia) 1910.

	Customary Measure	1909		1910	
		Quantity	Value	Quantity	Value
Gold, placer. .	Ounces.	. . . .	$ 477,000	. . . .	$ 540,000
Gold, lode.	"	238,224	4,924,090	267,701	5,533,380
Silver.	"	2,532,742	1,239,270	2,450,241	1,245,016
Lead.	Pounds.	44,396,346	1,709,259	34,658,746	1,386,350
Copper. . . .	"	45,597,245	5,918,522	38,243,934	4,871,512
Zinc.	"	. . . .	400,000	4,184,192	192,473
Coal.	Tons, 2,240lb.	2,006,476	7,022,666	2,800,046	9,800,161
Coke.	" "	258,703	1,552,218	218,029	1,308,174
Other materials	. . . .	. . . .	1,200,000	. . . .	1,500,000
			$24,443,025		$26,377,066

The tonnage of ore mined in the lode mines of the Province during the year was 2,216,428 tons, an increase over the preceding year of 7.7%.

This total tonnage was produced by the various districts in the following proportions: Boundary, 76.75%; Rossland, 11.35%; Fort Steele, 5.22%; Coast District, 1.90%; all other districts, 4.7%.

The number of mines from which shipments were made in 1910 was 83, and of these only 50 shipped more than 100 tons each during the year, while but 32 shipped in excess of 1,000 tons each. Of these latter, 8 were in the Nelson Mining Division, 8 in the Boundary District, 3 in the Ainsworth Division, 4 in the Slocan District, 3 in the Coast District, 3 in the Trail Creek (Rossland) Division, 2 in the Fort Steele Division, and 1 in the Trout Lake Division.

Taking the Province as a whole, there were 713 tons of ore mined a year for each man employed about the mines. In this respect, however, the districts vary very materially, since, in the Slocan, the figures show 148 tons mined to the man in a year; in the Nelson District, 142 tons; in Trail Creek District, 395 tons; and in the Boundary, 1,472 tons mined to the man employed.

READING AND DISCUSSION OF PAPERS.

The following papers were then read and discussed:—"MINING RIGHTS IN SEIGNIORIES IN THE PROVINCE OF QUEBEC," by MR. T. C. DENIS, of Quebec; "SILVER AND GOLD DEPOSITS ON THE

WEST FORK OF KETTLE RIVER, B.C." by Mr. L. REINECKE, of the Geological Survey, Ottawa; and "PHOTOGRAPHY FOR MINING ENGINEERS AND GEOLOGISTS," by Mr. H. MORTIMER-LAMB, of Montreal.

EXCURSION TO MONTMORENCY FALLS.

A considerable number of members and guests availed themselves of the opportunity, for which arrangements had been made, to visit Montmorency Falls. The party left the hotel at 2.30 p.m., under the guidance of Mr. T. DENIS, and spent a very pleasant afternoon, notwithstanding the inclemency of the weather which made tobogganing–one of the principal attractions of Montmorency in the winter season—impracticable. It should here be noted that the Quebec Electric Railway Company generously placed a large car at the disposal of the Institute for the occasion.

WEDNESDAY EVENING SESSION.

Upon re-assembling at 8.30 p.m., an instructive illustrated lecture, was delivered by PROF. J. F. KEMP, of Columbia University on "THE ENGINEERING PROBLEMS OF A GEOLOGICAL NATURE AFFORDED BY THE NEW CATSKILL AQUEDUCT OF NEW YORK CITY."

Dr. KEMP was followed by Dr. A. E. BARLOW, who showed upwards of a hundred slides illustrative of the Chibougamau region in Northern Quebec, which by direction of the Provincial Government was investigated last summer by a commission of which the lecturer was chairman.

THURSDAY, MARCH 2ND.

Two sessions, one in the morning and the other in the afternoon, were held during the day. At the morning session the following papers were read and discussed:—"THE TYPES AND MODES OF OCCURRENCE OF ASBESTOS IN THE UNITED STATES," by Dr. J. S. DILLER, of the U. S. Geological Survey, Washington, read, in the absence of the author, by Mr. J. A. DRESSER; "ASBESTOS DEPOSITS OF THE NEW ENGLAND STATES," by PROF. C. H. RICHARDSON, of Syracuse University, Syracuse, N.Y.; "THE

BREAKING OF ASBESTOS-BEARING ROCK," by Mr. EDWARD TORREY of Black Lake, Que.; and at the afternoon session "THE COPPER DEPOSITS OF THE KEEWEENAW PENINSULA, COMPARED WITH SIMILAR CANADIAN DEPOSITS," by Dr. A. C. LANE, of Tuft's College, Massachusetts; "RECENT DEVELOPMENTS IN PETROLEUM IN THE UNITED STATES," by Dr. D. T. DAY, of the U. S. Geological Survey, Washington; "THE GEOLOGY OF PETROLEUM," by Mr. EUGENE COSTE, of Toronto; "THE UNDEVELOPED COAL RESOURCES OF CANADA," by Mr. D. B. DOWLING, of the Geological Survey of Canada; "TELLURIUM ORES OF CANADA," by Dr. D. D. CAIRNS, of the Geological Survey of Canada; and "NOTES ON A DISCOVERY OF TELLURIDE GOLD ORES AT OPASTICA, AND THEIR PROBABLE RELATIONS TO THE GOLD ORES OF PORCUPINE," by Mr. ROBT. HARVIE, read in the absence of the author by Mr. T. DENIS. Mr. A. G. BURROWS presented an interesting summary of his report to the Ontario Bureau of Mines on THE PORCUPINE GOLD AREA.*

SMOKING CONCERT.

Under the direction of Mr. O. E. Le Roy and Mr. W. H. Boyd, of the Geological Survey of Canada, a capital programme was arranged for the Smoking Concert, which was held in the spacious tea-room of the Chateau on Thursday evening. Among the contributions more especially enjoyed was a lecture by Dr. Kemp illustrated by slides, describing his prodigious achievements as a mountaineer, and his miraculous escape from a disastrous end from a fall of apparently several thousand feet. The realistic rendering of the Institute's anthem "Drill, ye Tarriers, Drill," by Messrs. Brock, Le Roy and Boyd was also thoroughly enjoyed. The great event of the evening, however, was the trial for "Breach of Promise," of a distinguished ex-President, who, despite the misguided efforts of his counsel, Dr. Ledoux, was adjudged guilty and heavily fined. Mr. J. J. Penhale made an admirable Judge, while Mr. Boyd as the plaintiff was most *chic* and charming. Mr. Le Roy, as counsel for the plaintiff displayed great forensic ability, and the principal witnesses, Dr. Kemp (who, by-the-way, gave his name as Cook) and Dr. Adams also distinguished themselves. The lemon, produced in Court, was the determining factor.

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*Report XX, Ontario Bureau of Mines, Part. 2, 1911.

FRIDAY, MARCH 3RD.

The reading and discussion of papers were resumed at 10 a.m., as follows:—"RECENT UNDERGROUND DEVELOPMENT WORK AT COBALT," by Mr. C. W. KNIGHT, of Toronto (illustrated by lantern slides from photographs taken by Mr. Arthur A. Cole);"THE IRON ORE RESOURCES OF THE WORLD," by Dr. F. D. ADAMS, of Montreal; "THE IRON ORES OF THE METTAGAMI RIVER," by Prof. M. B. BAKER, of Kingston; "SOME SUGGESTIVE PHASES OF THE IRON MINING INDUSTRY OF EASTERN NORTH AMERICA," by Mr. FRANK L. NASON, of West Haven, Conn.; "EARTHQUAKES AND MINES," by Dr. JAMES DOUGLAS, of New York; "THE CLAYS OF WESTERN CANADA," by Dr. HEINRICH RIES, of Cornell University, Ithaca, N.Y.; "THE SLATE INDUSTRY IN THE PROVINCE OF QUEBEC," by Mr. J. A. DRESSER, of Ottawa; "ZINC, AND THE TREATMENT OF DIFFICULT ORES," by Mr. W. R. INGALLS, Editor of the *Engineering and Mining Journal*, of New York; and an address on the subject of the "UNITED STATES TESTING PLANT FOR EXPLOSIVES," by Mr. G. S. RICE, a member of the staff of the United States Bureau of Mines. Mr. RICE said:—

"It is suggested that I briefly outline the organization and work of the United States Bureau of Mines, information concerning which may be of use to Canadians. I became associated with the department some two years ago when investigation and affairs connected with the practical operation of mines were entrusted to the technological branch of the U.S. Geological Survey. Our first task, initiated at the St. Louis Exhibition under the direction of Dr. Holmes, Mr. Parker and other members of the Geological Survey, was the testing of fuels with a view particularly to ascertaining and demonstrating the possibility of the further utilisation of low grade materials for fuel purposes. The plant established at St. Louis was subsequently moved to the Jamestown Exhibition, and later again to Pittsburg.

"The year 1907 witnessed the continuation of a long series of coal mine disasters in the United States that had awaked anxiety among operators, more especially as a large percentage of the explosions had occurred in highly developed mines. During one month in that year some six hundred men were fatally injured. Congress was petitioned to take cognizance of conditions and voted money for an investigation, which was undertaken by the Technological Branch of the Geological Survey, under the direction of Dr. Holmes. After a study of the protection and preventive methods in force in Europe by myself and others, it was decided to establish a testing plant at Pittsburg, as being the centre of the greatest coal producing area of the country and also by reason of the fact that it is within easy reach of Washington, the administrative headquarters. Actual testing operations were inaugurated on January 1st, 1909, and manufacturers of explosives were invited to send their products for test, the passing of which would entitle such an explosive to a place on the permissible list. This term was employed since there was no legal obligation on manufacturers to respond to the invitation and the Department could not restrict the use of explosives to such as had satisfactorily passed the test; but it was believed that the creation of such a classification would have a moral effect and this has proved to be the case.

"It may not be generally known that explosions in coal mines have in a great majority of instances resulted from the use of long flame explosives and more especially black powder. Our aim, therefore, has been to bring about the general employment of short flame explosives, which will not ignite coal-dust or fire-damp."

Mr. Rice further remarked that in point of fact explosions in coal mines were not responsible by any means for the larger percentage of fatalities, a greater number of lives being lost annually as a result of falls off roofs and machinery accidents. In 1907, for example, the year of great colliery disasters in the United States, the actual number of deaths directly attributable to explosions was 1,100, whereas over 2,000 deaths were reported from other mentioned causes. It is, meanwhile, interesting to learn that the death rate from mine accidents in the United States showed a decrease in 1908, and again in 1909.

The United States Bureau of Mines has at present a fuel division and a mines' accident division. A metallurgical division has not as yet been organized, but arrangements will probably be made to engage the services of eminent practising metallurgists from time to time to undertake special work or investigations.

Mr. JAMES MCEVOY having first referred appreciatively to Mr. Rice's interesting account of the work of the United States Bureau of Mines, said: "Mr. Rice has alluded to certain coal mine practices which he very properly points out should not be permitted. For example, the shooting of the 'solid,' and the use of electricity for power should be absolutely prohibited in gaseous mines.

"The questions with which this Bureau must necessarily deal are most serious and important. In the United States (and this is also the case in some parts of Canada) mine organization as regards efficiency of production is very thorough; but decidedly lax in the insistence of attention to rules and regulations, and in the provision of precautionary measures designed to minimize danger to life and property.

"Much, however, may be accomplished by more thorough laws, and by insisting on their observation to the letter. It must not be forgotten that in some quarters, unfortunately, there is a tendency to evade the laws.

"It has always seemed to me that undue prominence is given to coal dust in connection with explosions. Dust will of course play a contributory part in an explosion; but the real danger is gas. If therefore more attention were devoted to the question of ventilation, and provision for the circulation of the proper quantity of air, through, not only the main air ways, but at every working face, the likelihood of explosions would be reduced to a minimum. To provide for the safety of a coal mine, adequate ventilation is the indispensable condition."

GENERAL BUSINESS—THE WESTERN BRANCH.

The PRESIDENT invited the attention of members to a question that had arisen during the past year in connection with the finances of the Western Branch. He pointed out "that some two years ago, it was decided to rescind Rule 7 of the 'Regulations for the Government of Branches,' providing for the granting of financial aid to Branches. An exception, however, was made by the Council, on the recommendation of the Finance Committee, in the case of the Western Branch, which continued therefore to receive assistance equivalent to 25% of the annual subscriptions to the

Institute received from Western members; and as a matter of fact the amount was exceeded. In October, 1909, representations were made that the assistance thus granted was inadequate. To this notification the Council replied that the appropriation could not be increased, but that if additional funds, over and above the 25% remission were required 'the Branch would be expected to arrange its own finances.' It may here be interpolated that at an earlier date the Branch had been urged by the Council to secure, if possible, a grant for the Institute from the British Columbia Government, which, it was mentioned, would enable the Council to provide more generously for the maintenance of a Western Branch. But the suggestion that the Branch should arrange its own finances was interpreted as an authorization from the Council to the Branch to secure for its own purposes financial assistance from any source, including the Provincial Government, and application was accordingly made to the latter for a grant. This application was successful and a grant was obtained payable directly to the Branch instead of to the Institute. Although contrary to a principle previously enunciated by Council, the Branch was permitted to retain the Provincial grant; but in making this concession the Council took the view that the original understanding as they conceived it, governed the case and therefore discontinued the remittances on the membership basis. This arrangement, however, failed to satisfy the Branch, who contended that the monthly remittances should not be discontinued without ample formal notice that such was the Council's intention. A lengthy correspondence has resulted. The Council has meanwhile conscientiously endeavoured to bring the matter to a conclusion satisfactory to the Western Branch and at the same time fair to the membership in general. With this aim in view a telegram was despatched to the Chairman a day or so ago inviting him to offer any suggestions likely to bring about an amicable settlement of the dispute, and the following reply was received from him yesterday:—

'"The Western Branch requests annual meeting to authorize committee of three, one appointed by council, one by branch, the two to select third member to settle question. Committee's decision to be final. Terms of government grant to Branch not to be open to arbitration.'

"The Council assembled to consider this proposal, but it did not commend itself to the members present, for they unanimously adopted two resolutions which I am desired to submit for your endorsation or otherwise:—

"(1). 'That in future no annual grant be made by the Institute to any of its Branches.'

"(2). 'That in view of the present misunderstanding in regard to the financial assistance that the Western Branch should receive from the Institute, and in order to effect a final settlement of the matter, be it resolved that the Branch be paid, in addition to the grant received by them from the British Columbia Government, the balance of a sum equivalent to 25% of the fees received from Western members during the year 1910, and proportionately to March 1st, 1911.'

"In other words, the Council here intimated that if an error was made in not notifying the Branch in advance that the remittance from the Institute would be discontinued, any cause for grievance or complaint on this score will now be removed by refunding the amount claimed for the year 1910 to date."

On motion of Mr. JAMES WHITE, seconded by Mr. J. W. EVANS the action of the Council was approved and confirmed.

Mr. COSTE then moved the following resolution, which was seconded by Mr. W. J. DICK and carried unanimously:—

"RESOLVED:—That in view of the passage of the above resolutions by the Council, this meeting deems the appointment of a Board of Arbitration unnecessary."

Mr. COSTE then explained that he had been largely responsible for the introduction and adoption of the policy of establishing Branches of the Institute throughout the country. But it was never contemplated to permit of the organization of Provincial sections, which would simply mean a reversion to the old order of affairs of provincial organizations and would tend to the ultimate disruption of the Institute. Branches in local centres where there is any considerable membership, such for example, as Sherbrooke, Montreal, Toronto or Cobalt serve a most useful purpose. The members meet at periodical intervals for either social or business purposes, and each contributes his share towards the local expenses. Such organizations are no charge on the Institute; but, on the other hand, are of assistance, since they serve to conserve and promote interest and are largely instrumental in introducing new members. Mr. Coste considered that the council should notify the Western members to this effect, and arrange for the establishment of several branches at important centres such as Nelson, Rossland and Vancouver.

Mr. JAMES WHITE expressed the opinion that any such action at the present time would not be politic.

Mr. McEVOY agreed that to pass a resolution in line with Mr. Coste's views would be inopportune; but considered that a suggestion from the meeting to the Council to discuss with the Western Branch its re-organization in keeping with the constitution of the Institute would be of value.

The PRESIDENT remarked that the Council had already expressed the hope that by holding semi-annual meetings of the Institute in the West, all present difficulties would be speedily dissipated and differences of outlook reconciled. It was, he added, directly attributable to the fact that Western members were unable to attend the annual meetings that any difficulties or misunderstandings had arisen.

On motion, votes of thanks were tendered to the President, Dr. F. D. Adams, "for the able, efficient and courteous manner in which he had conducted the meeting; to Dr. J. B. Porter for the loan and operation of the lantern throughout the sessions; to the members, Messrs. J. J. Penhale and T. Denis, of the local organization committee; to Messrs. Boyd and Le Roy of the entertainment committee; to Col. Turnbull and Mr. J. G. Scott for the entertainment of members at the Garrison Club; and to the Quebec Street Railway Company for generously providing members with free transportation over its system during the three days of the meeting.

ANNUAL DINNER.

The Annual Dinner was served in the Tea Room of the Chateau, which was handsomely decorated for the occasion. Covers were laid for a hundred in the main hall; while in an adjoining small room provision was made for a number of ladies, the wives of members in attendance, who were entertained by Mr. T. Denis. The menus were printed on asbestos shingles, presented by the Asbestos Manufacturing Company, of Montreal.

After the formal toast, "The King," had been duly honoured, the toastmaster, Mr. J. J. Penhale, read the following telegram, addressed to the Secretary and signed by Mr. E. Jacobs:—

"Western Branch sends cordial greetings to parent Institute and its hearty good wishes for successful annual meeting. Branch council regrets it has not been practicable to send to Quebec representative. Please present our compliments to United States visitors, in welcoming whom we desire to join."

Letters and telegrams expressing regret at inability to be present were also read from His Excellency, the Governor General, Sir Wilfrid Laurier, the Hon. R. L. Borden, the Hon. W. S. Fielding, the Hon. Wm. Templeman, the Hon. Senator Bostock, the Hon. James Whitney, Mr. J. Parke Channing, Mr. John Taylor, President of the Institute of Mining and Metallurgy, Mr. D. W. Brunton, Dr. H. E. Gregory, Mr. Wm. Frecheville, Prof. R. H. Richards, Mr. B. B. Lawrence, Major R. G. Leckie and others.

The principal speakers of the evening were Mr. F. T. Congdon, M.P., who eloquently responded to the toast "The Dominion Government"; the Hon. C. R. Devlin, Dr. James Douglas, Mr. John E. Hardman, Dr. W. G. Miller, Dr. J. F. Kemp, Dr. A. C. Lane, Mr. F. L. Garrison, Mr. A. M. Hay, Mr. Eugene B. Wilson and Mr. J. C. Murray.

WESTERN BRANCH.

Nanaimo, B. C., Feb. 17th and 18th, 1911.

A meeting of the Western Branch, the ninth of the series, was held at Nanaimo, B.C., on February 17th. The members were welcomed by Mr. Alderman Shaw, who represented the City in the absence of the Mayor.

Mr. E. B. McKay also addressed the meeting, giving some interesting information concerning the early history of mining in the vicinity.

The following papers were read: "First Aid; its Relation to Coal Mining", by Mr. Chas. Graham, Superintendent of the Nicola Valley Coal & Coke Co., Middlesboro, B.C.; "Coal Mining in British Columbia", by Mr. C. F. J. Galloway, of Vancouver; "The Beginning of Coal Mining in British Columbia", by Mr. W. Fleet Robertson, of Victoria, B.C.; and "Earthquake Strains and Stresses in Relation to Coal Mining Explosions", by Mr. F. Napier Denison, of Victoria, B.C.

Upon the invitation of Mr. Thos. Graham, Superintendent of the Western Fuel Company's collieries, the members visited, on the second day of the meeting, that company's plant, and witnessed a demonstration with the Draeger apparatus.

The Chairman, Mr. Robertson, announced that the Department of Mines of the United States Government had granted certificates to the following mine inspectors in British Columbia, who had taken a course in the United States Government's life saving station at Seattle: Messrs. J. Newton, W. Evans, J. Strachan, McTiskie and T. Morgan.

The Secretary, Mr. Jacobs, called attention to the heroic action of the late Fred Alderson, a Hosmer miner, who lost his life in endeavouring to rescue the victims of the Bellevue explosion. On motion of Mr. Thos. Graham, a vote of thanks was tendered the Provincial Government for having contributed the sum of five hundred dollars ($500.00) towards a memorial fund.

Before the close of the meeting the Chairman reported that a grant to the Branch of one thousand dollars ($1,000.00) had been included in the Provincial Government's estimates for the current year.

TRAIL, B. C., MAY 18th and 19th.

A meeting of the Western Branch, the tenth of the series, was held at Trail on May 18th, Mr. W. Fleet Robertson, Chairman of the Branch, presided.

The following papers were presented: "The Burns Anthracite Coal Property, Alberta," by Alexander Sharp; "Costs of Operations at the Blue Bell Mine, Kootenay Lake, B.C.," by S. S. Fowler; "Notes on Property of the Le Roi No. 2, Limited, at Rossland, B.C.," by Ernest Levy; "The Standard Mine, Silverton, B.C.," by John Valance; and (by title only) "Notes on the Lucky Jim Zinc Mine, Slocan, B.C.," by A. J. Becker; "The Van-Roi Mining Company's Concentrating Mill, Four-mile Creek, Slocan," and a description of the copper smelting side of the Consolidated Mining and Smelting Company's smeltry at Trail.

Mr. H. Mortimer-Lamb, Secretary of the Institute, who was present, explained the suggestion of the Council that arrangements in future should be made for holding a regular semi-Annual Meeting of the Institute in the West. This meeting, it was proposed, would probably be held in October of each year. On motion of Mr. Robertson, seconded by Mr. Keffer, the suggestion of the Council was endorsed.

The result of the ballot for Chairman and members of the Branch Council for the ensuing year was as follows: Chairman, Robt. R. Hedley; Secretary, E. Jacobs; Councillors, W. H. Armstrong, S. G. Blaylock, S. S. Fowler, Norman Fraser, Thos.Graham, J. Cleveland Haas, John Hopp, W. H. Trewartha-Jones, Frederic Keffer, Thos. Kiddie, F. C. Merry, M. E. Purcell, W. F. Robertson, Lewis Stockett, O. E. S. Whiteside, and W. E. Zwicky. Mr. Hedley presided during the latter part of the evening session.

On Friday morning, May 19th, some of the visitors were shown through the Consolidated Mining and Smelting Company's copper and lead smelting works and electrolytic lead refinery at Trail, and in the afternoon spent several hours in the Company's Centre Star Mines, at Rossland.

NEW DENVER, B. C., SEPT. 13th and 14th.

A most successful and largely attended autumn meeting of this Branch was held on the above date.

EASTERN TOWNSHIPS BRANCH.

SHERBROOKE, QUE., MAY 12th, 1911.

A meeting of the Eastern Townships Branch was held at Sherbrooke on May 12th. Mr. J. J. Penhale, Chairman of the Branch, presided. Several papers were presented, and were productive of interesting discussions.

McGILL MINING SOCIETY.

(Reported by W. W. BOYD, Secretary).

During the past college year meetings of this society have not been so numerous as in previous years. Six meetings were, however, held, at four of which papers were read, these being: "The Conservation of the Resources of Canada", by Dr. James Douglas; "Photography for Mining Engineers and Geologists", by H. Mortimer-Lamb, Esq.; "The Examination of Undeveloped Mining Properties", by W. Dixon Craig, Esq., and "The Ore Deposits of Sweden", by Dean Adams. The membership this year is not so large as that of 1909–1910 there being only 46 compared to 53 members. This may be accounted for by the fact that neither the 3rd nor 4th year is as large this year as last year.

On the whole, the Society is in a very healthy condition.

Three of our members attended the Convention of the Canadian Mining Institute at Quebec this spring.

The officers for the year 1911–1912, were elected on March 17th, at the last regular meeting. They are:—

Hon. President.—Dr. J. B. Porter.
President.—A. E. W. Hannington.
Vice-President.—Lawrence Gass.
Sec.-Treas.—Clarence McEvenue.

PROFESSIONAL PAPERS

EARTHQUAKES IN MINES.

By JAMES DOUGLAS, New York.

(Annual Meeting, Quebec, 1911.)

Here in Quebec we are meeting at what is almost a focus of earthquake activity, and where earthquakes have been events of some historical importance. The seismic area extends from beyond the St. Lawrence valley to the Atlantic coast, and therefore these startling visitations, in the colonial days of New France and New England, surprised the English as well as the Canadians, and were by both supposed to be either the messengers of providence sent to convey a divine warning, or else the work of the devil—an easier way of explaining their origin than some of our modern theories. Winthrop in his journal records a violent shock in April, 1638, and another in May, 1642. Bradford tells of an earthquake in 1640 which had the effect of deciding certain dissatisfied Pilgrims not to break up the community. He says: "It so fell oute yt at ye same time diverse of ye cheefe of this towne were mette together at one house, conferring with some of their friends that were upon their removall from ye place (as if ye Lord would herby shew ye signes of his displeasure, in thus a peeces and removalls one from another)."

At the same time Bradford was looking for some natural cause for the occurrence. He observes: "Ye somers, for divers years togeather after this earthquake were not so hotte and seasonable for ye ripening of corne and other fruits as formerly; but more could and moyst, and subjecte to erly and untimly frosts, by which many times much Indian corne came not to maturitie; but whether this was any cause, I leave it to naturalists to judge."

In Canada, the Jesuit Relations and the Jesuits' Journal mention at least six distinct earthquakes in the seventeenth century. The most sensational was that of 1663. Quebec was startled by an earthquake at Easter-time of that year, just when Bishop Laval and his clergy were fighting for the cause of temperance. The Bishop was a Montmorency and, like his forbears, enjoyed a fight. He had excommunicated all who were engaged in the liquor traffic and had sailed for France to lay before the King a formal complaint against the Governor, and defend his own position. During his absence the Jesuits did their best to carry out his policy. But while the good fathers were willing to use all the powers of the church and of the state to check the demoralization of their converts through the use of ardent spirits, they were by no means total abstainers themselves, or advocates of it. Just then, indeed, a little occurrence within their own doors showed what embarrassing accidents may happen in the best regulated communities. It was their custom to give their choristers beer, and at Christmas time they supplemented it with a flask of wine. That might not have done much harm; but the chief warden, without their knowledge, duplicated the dose, which proved too much for the youngsters. That such a catastrophe, which it was impossible to conceal, should have happened at a moment when they were thundering excommunications against all persons, high or low, guilty of selling drink to the savages, was, to say the least, annoying, and must have exposed the reverend gentlemen to not a little irreverent chaff.

Unfortunately crime was rife. La Badande's house was rifled by thieves, and then burnt to conceal the robbery; but the criminal, one Larose, was speedily apprehended and hanged. Other thieves were caught, but so lax had become the standard of civil authority, or so antagonistic the attitude of the civil officials towards the reverend conservators of public morals, that no conviction could be secured. The fathers were in despair, when the whole country was suddenly frightened into a sense of its wickedness by the most violent earthquake on record in Canada. The focus of greatest disturbance was then, as subsequently, at or near Baie St. Paul, some sixty miles below Quebec, where a little hill is described as toppling into the river, and then through the elevation of the land, reappearing as an island.

Quebec, near the centre of the movement, felt the shocks acutely. Father Lalemant described the movement as less violent in elevated localities than in low-lying ones; it is probable, therefore, that the shores of the St. Lawrence and the lower town were more violently shaken than the upper town.

There had been premonitions for months previously of an impending convulsion, aerial voices, fiery serpents flying through the air, magnificent double suns, and a solar eclipse with other natural and some abnormal phenomena—all interpreted afterwards as supernatural warnings. All passed unheeded, however, until half-past five on Shrove Monday, 1663, when the people were preparing for the feasting and revelry of Shrove Tuesday. Suddenly there was a noise as of a furious conflagration, followed by a rocking motion, which overturned household articles, cracked walls from cellar to roof, threw down chimneys, crushed the ice on the river, shivering it into splinters, and terrified the whole population into such an access of piety that "Shrove Tuesday was happily converted into Good Friday," to use the Jesuit description, and the rush to the confessionals kept the priests busy all night. But the reformation was short lived, as Father Lalemant is willing to confess in his letter to the General of the Order, which was not intended for publication. "The whole region," he says, "was shaken at one and the same time by a violent earthquake on the 5th day of February. It was not continuous, but intermittent—now more, now less violent. There was a wonderful commotion of men's minds at the start, producing conversions, both among the French and the natives; but these were so transitory that an increase, rather than a decrease, of the scourge was deserved by many. However, no notable loss was felt, if you except the loss of some chimneys, which immunity is rightly attributed to the special favour of God. These things seem proper to be written to you fraternally in this my private letter. I send another—a public one—with matters more fully considered as regards our plans about combatting future wants."*

Physical fear was intensified by superstitious terror and belief in the interference of supernatural and malevolent agencies. Mère Marie de l'Incarnation, the Superior of the Ursuline convent, expressed the current opinion when she tells us that "the devils

*Thewaite's Jesuit Relations 47, page 255.

undoubtedly mix themselves up with natural occurrences." As always happens, the further removed the phenomena were from the actual observation of the narrators, the more extraordinary they were described as being. At Three Rivers, when the rocks were cracking and actually disappearing, a horrid, shapeless and monstrous spectre was seen crossing from east to west along the edge of the moat constructed for the military defence of the town. At Montreal the terror was less, because, as the Church declared, the consciences of the pious people were not disturbed on account of their sins—more probably because, owing to the greater distance from the centre of disturbance, the shocks were less violent.

The fissuring of the rocks was probably as true as the appearance of the horrid and monstrous spectre. Nevertheless, *Les Eboulements*, a prominent rock escarpment on the lower St. Lawrence, derived its name from a landslide occasioned by the great earthquake of 1663.

My object in referring to this earthquake is not to direct attention to an interesting local tradition, but to ask for co-operation of members, as mining engineers, in making a comparison between the seismic phenomena at surface and seismic phenomena below the surface. The velocity and amplitude of the waves may be influenced by the relations between the strike and dip of the rocks and the direction along which the shock is proceeding through them; and comparative observations in the same mine might throw some light on the effect which depth and therefore pressure exert both on the velocity and amplitude of the waves.

I have referred to the historic earthquakes in this region. They continue to affect it. While I was interested in the working of the Harvey Hill mine in this province, there was an earthquake, violent enough to crack thick stone walls, in the valley of the St. Lawrence. My recollection is that the movement was very perceptible at the surface of the mine, but not noticeable enough underground to excite observation. Shortly after that I spent nearly a year on the west coast of South America, and visited most of the large copper properties of Chili, then at the period of their greatest activity and productivity. Slight vibrations and rumblings were almost of daily occurrence along the west coast, but I did not happen to experience a destructive earthquake. One had, however, occurred the previous year, and in passing

Arica I saw nothing but the site of a once prosperous town, the ruins of which, occasioned by the earthquake, had been almost completely swept away by the wave, which followed the shock half an hour later and which carried the American gunboat "Wateree" and the Peruvian frigate "America" half a mile inshore. The damage done was to buildings on alluvial soil, for the town was built in a valley at the base of a high cliff. To it the people had fled for safety from the earthquake before the wave overwhelmed the town.

In Chili I made inquiry at every mine I visited as to the damage done underground by earthquakes; and I could not learn that in a single instance even a stick of timber had been dislodged or a shaft put out of plumb.

Subsequently, in May, 1887, northern Sonora and southern Arizona were violently shaken by a series of earthquake shocks. The focus of the disturbance was near Bavispe, a small town, in the valley of the Bavispe river, on the west slope of the Sierra Madre. It was completely wrecked. And as the first shock occurred in the afternoon, when the people were taking their siesta, the mortality was high. Out of a population of about seven hundred, one hundred and sixty-nine were buried under a hundred and fifty fallen buildings, and there were forty-six fatalities.

Bisbee and the Copper Queen mines and works are about a hundred miles to the north-west of Bavispe. There the first shock occurred shortly after it had destroyed Bavispe; but no observations were taken at either place to determine the direction or velocity of the earth waves. In Bisbee the shock was violent enough to dislodge loose rock from the waste heaps, to crack a slag dump resting on alluvial soil, to injure a recently built foundation of a Corliss engine, and to rupture adobe walls. But no house was thrown down. In the Copper Queen mine the shock was felt and great alarm created, but no rocks or timbers were dislodged. The shocks continued for over a month with decreasing intensity. Several days after the first shock I was underground with a foreman of the mine, exploring one of the narrow caves in the limestone rocks, which there generally indicate the proximity of an ore body, when a shock of very considerable violence occurred. The sensation was as though the wall of the cave were approaching and would completely crush us. As a matter of fact, however, not a particle of rock was dislodged and, after the event, we wondered whether our imagination had not played us false.

In the region of the mine there certainly was no fissuring of the rocks. But in the Sulphur Spring valley long fissures were cleft in the soil and small craterettes produced, from which water was ejected in large quantities. This valley lies between mountain ranges for a hundred miles, and has a width of nearly twenty miles. It is filled with detritus from the adjacent ranges to a very great depth, bore holes of over 900 feet depth not having reached rock. But though the surface is dry, except during floods, water can be tapped in large quantities at a depth of not over thirty feet. In Sonora, craterettes and fissures were formed in the Fronteras valley, while on the west flank of the San Bernardino range and along a broad alluvial basin, there was a rupture in the alluvial deposit which extended in a general north and south direction for many miles, and could be distinctly seen from a distance of eight or ten miles. I sent a competent person to examine it; but so far as observation could determine, there was no evidence of actual rock fissuring. In fact, I believe authorities attribute 90% to 98% of earthquakes to the elastic movement of the earth's crust, and this proportion is probably too low; for immediately after an earthquake the men are seldom calm enough to observe accurately. In the San Pedro valley to the west of Bisbee, where the soil was deep and saturated with water, the motion was sufficiently violent to throw down buildings and to produce a distinct sense of nausea. Dr. Goodfellow, a competent recorder, was in Tombstone, 30 miles north-west of Bisbee. He reported that " men working at a depth of 600 feet felt the vibrations severely. Men working at 150 feet, did not notice it so much. One crew of men at that depth did not know of it at all till they came up out of the mine." The earthquake was felt distinctly down the San Pedro valley to its junction with the Gila, a distance of about one hundred miles, to the north-west of Bisbee, Here the waves were evidently so interrupted by the Pinal mountains that the shock was not perceptible beyond the range at Globe, twenty miles farther north.

The earthquake occurred during the driest season, when the grass on the mountain ranges was thoroughly parched. On the evening of the earthquake every mountain range within sight of Bisbee was on fire, and the prevalent opinion was that craters had broken out on all sides and that masses of lava were issuing from them. This opinion is still held. In fact, there were no ruptures anywhere, so far as observations went, of the rock surfaces. The fires were probably ignited by stones rolling down the hillside, striking sparks and igniting the dry grass and leaves.

Every destructive earthquake has wrought most damage on alluvial soil, especially if it be moist. That was notably the case in the Charleston and San Francisco earthquakes. If one adopts the commonly accepted figures for the rapidity with which earth-waves are propagated, namely, 5,000 to 6,000 feet per second through solid rock, 1,000 to 800 feet per second in gravel and sand very much less when the soil is saturated by water, one can easily appreciate how the passage from one class of material, or from dry material through moist material, must aggravate the effects of the disturbance. Moreover, the velocity, as well as the amplitude of the waves, must be influenced largely by the character of the rock, and by the obstruction offered by rocks whose strike is at a more or less acute angle to the direction of the shocks.

Questions of this kind can be studied most satisfactorily by seismic observations in our mines. A series of seismographs from surface downwards in the deep shafts of the Tamarack and the Calumet and Hecla mines might give very interesting comparative figures. The mines with which I am connected do not, I am happy to say, penetrate so far into the earth's crust; but in the most important of them, being in limestone which has been naturally and artificially fissured, a seismograph record might afford some interesting data as to the effect of such obstructions on earth movements. At any rate, I intend to instal such instruments, and should others do likewise, the facts that we observe and record may help to give some stability to the very unstable science of seismography.

DISCUSSION.

DR. DOUGLAS (Communication to the Secretary.)—Since the Quebec Meeting an interesting paper by Prof. J. W. Gregory on the Glasgow Earthquake (of Dec. 4th, 1910) in relation to Mining, has been published in the Transactions of the Institution of Mining Engineers. Prof. Gregory's opening paragraph emphasizes what I learned to be the case in Chili. He says:—

"Earthquake phenomena present several problems of special interest to miners, although the actual shocks may be less felt underground than on the surface. Thus it has often happened that an earthquake which has done serious damage has not been felt by men at work underground. For example, the disastrous earthquake in Northern India of June 12th, 1897 passed unnoticed in some Bengal coal-mines. Nevertheless, earthquakes may produce several important mining effects. They may lead to slight dislocations which may cause falls of roof; or they may produce strains which are relieved by sudden rock explosions or "air-blasts," such as have long been known in Cornwall, and are especially frequent and fatal in the Kolar gold-field in Mysore, where they have been carefully investigated by Dr. Smeeth."

The author is inclined to attribute the dangerous escape of gases in coal mines to earth movements, sensible or insensible. The use of the seismograph underground might afford proof, instead of speculation, on some points, and if those proofs were obtained, might be an instrument of protection.

The article is interesting as referring to a larger mass of literature upon the subject than I knew to exist.

MR. COSTE:—I have been very much interested in the statements in Dr. Douglas' paper and, in this connection of earthquake activity along the St. Lawrence valley, between Montreal and Quebec, I would like to call attention to an old report of the Jesuit fathers in which they state that at one time after most pronounced earthquake shocks, the surface of the water in the St. Lawrence river was found to be so covered with petroleum that the water was not drinkable. There are many other instances on record to show that after earthquake shocks enormous quantities of natural gas and petroleum have come to the surface in many parts of the world, and it is no doubt due not only to the fissuring induced in the strata, by dynamic disturbances and earthquake shocks, but also to the fact that in many instances faulting and fissuring of the strata during such disturbances extend to great depths from which hydrocarbon volcanic emanations ascend to the surface or towards the surface themselves in the porous strata encountered on the way up. For instance, as cited by Mr. A. Beeby Thompson in his recent book on "Petroleum Mining," on the 21st of December, 1897, a disturbance, occasioned by an earthquake, led to the formation of a mud volcano beneath the sea off the southern point of the Klias peninsula of Borneo, when sufficient argillaceous material was ejected to form a new island several hundred feet long, several hundred feet wide and twenty feet above the sea level. Large quantities of inflammable gases and vapours of petroleum were constantly ejected from the crater of the mud volcano.

A similar mud volcano, of very large extent, was formed off the Burma Coast, on the 15th December, 1907, when sufficient material was also ejected to form a large new island upon which a landing was effected by the officers of a British marine survey ship shortly after the eruption, when the mud still indicated a temperature of 148° F., a few feet below the surface. A very renowned chain of mud volcanoes exists in the Arakan Islands off the coast of Burma and they often display unusual activity during earthquake disturbances.

In the Poota and Binagadi districts near Baku (Russia) there are a number of mounds which display violent activities occasionally and the gas then bursts forth in immense volumes through numerous rents blown in the sides, and the heat emitted by the burning gas, which ignites spontaneously, is intense; the glare is distinctly visible from Baku, ten to twelve miles away.

Many other similar examples connecting petroleum with volcanic activity and dynamic disturbances could be cited from many other parts of the world notably Alaska, Japan, Borneo, Java, Trinidad, etc.

EARTHQUAKES, STRAINS AND STRESSES IN RELATION TO MINE EXPLOSIONS.

By F. Napier Denison, F.R. Met. Soc.

Meteorological Office, Victoria, B.C.

(Western Branch Meeting, Nanaimo, February, 1911.)

During the last few years we have been deeply impressed by the unusual number of coal mine explosions which have occurred throughout the world; and, in the hope that certain studies carried on by the writer during the last twelve years might aid in determining the causes of these disasters, a short account of this work is presented.

In the autumn of 1898 a Milne Seismograph, or horizontal pendulum, was installed at Victoria in connection with the meteorological office established here. It forms one of many throughout the world whose records of quakes furnish valuable information for the Seismological Committee of the British Association for the Advancement of Science.

In order to fully understand much that will follow, it is necessary to give a brief description of Prof. Milne's seismograph. The instrument consists of a metal upright and base with three levelling screws, placed upon a concrete pillar. A few inches from the lower end of the upright is a fine steel point, upon which rests one end of a boom which is one metre in length. This boom is very light, being made of aluminium; it is supported by a fine wire attached a short distance from its pivot end. This wire rises to the top of the metal upright, where it is connected to an adjusting screw. A balance weight attached to the boom between the point of suspension and pivot reduces the friction at the pivot-point to a minimum. By adjusting the levelling screws in the base of the instrument the upright is made perpendicular, and the free end of the boom or horizontal pendulum comes to rest.

When the waves from a distant quake reach the station, they tend to rock the concrete pier; this throws the metal upright out of perpendicular, and the movement, though too small for one to notice, causes the boom to swing.

To record these movements, a small plate is attached to the free end of the boom, and under this is a fine slit in a case containing a roll of photographic paper, which, by clockwork, passes continuously the slit in the top of the case.

By means of a mirror, a constant ray of light is reflected on to the floating plate and that portion of the slit not covered by the plate. When the boom is steady, a dark straight band is photographed on the moving paper below; but when the plate is swinging across the slit, a wavy line is recorded, called a seismogram.

This instrument is so sensitive that when the boom is at rest the slight pressure of a finger on its concrete pier will start it swinging slightly. The time of vibration of this instrument is 15 seconds, being the standard adopted at most stations where Milne seismographs are in operation.

The waves set up by a distant earthquake are of various forms. The first to reach a station take the shortest course through the earth, and are called longitudinal waves. Then follow transverse ones, while the largest waves travel along the earth's surface. The latter affect the instrument most noticeably, as they pass under the station; and when the quake has occurred nearby, these surface waves are the destructive ones.

A study of the Seismological Chart of the World recently published by Prof. Milne, as Secretary of the B. A. A. S. Committee, illustrates where all the great earthquakes have occurred during 1909. It gives the names of the stations where Milne seismographs are in operation and, it may here be noted in passing, that there are now sixty Milne seismographs in operation in the world.

On this chart the zones of earthquake intensity are shown. The region where the greatest number of quakes occurred during the past two years lies beneath the ocean, extending from Java and the Philippine Islands in an E.S.E. direction towards the middle of the Pacific.

Prof. Milne suggests this points to a continent in the making.

Another seismic zone extends northward along the eastern coasts of Formosa and Japan, thence through the Aleutian Islands to the mainland of Alaska, thence southward along the coasts of both North and South America.

Another zone girdles the earth, and includes the West Indies, the Azores, the Mediterranean, Asia Minor and India. These zones are located along lines of weakness in the earth's crust, and usually where there are great ocean depths and high continental ranges.

The chart giving the distribution of active volcanoes shows these to be also mostly in the vicinity of the same lines of weakness.

Turning our attention to the North and South American earthquake zone, it is interesting to note the evidences of periodic earth stresses along this line. In 1906, when in conversation with Dr. Omori, of Tokio, who visited Victoria on his way to study the San Francisco quake, the latter stated that the great Alaskan quakes of September 4 and 11, 1899, and October 9, 1900, had partly relieved this strain; then followed the great quakes of April and September, 1902, which strongly shook Mexico and Central America. Finally, on January 31, 1906, Panama and the coasts of Columbia and Equador were badly shaken. He pointed out that the San Francisco quake completed the chain of seismic activity and removed a state of great unstability in the earth's crust along the North American coast, and that this district would be free from great shocks for a period ranging from 20 to 30 years.

He also stated that the next seismic disturbance was likely to occur on the coasts of Peru or Chile. This actually occurred on the 17th August, 1906, when awful destruction befell Valparaiso.

The great San Francisco quake demonstrated the value of reinforced concrete as a building material to withstand severe shocks.

A copy of the Victoria record of this great disturbance shows first a small vibration, followed in a little over a minute by violent oscillations, causing the boom to swing completely across the paper. The first tremor came directly through the earth to Victoria, while the commencement of the great swing indicates the arrival of the surface waves on their journey around the world. Therefore, the nearer the station is to the place where the quake occurs, the closer will the first tremor and the surface wave be on the record. To illustrate this: The record of the small quake felt here on January 11, 1909, showed an almost instantaneous large swing without any preliminary tremor. This indicated that the point of origin was comparatively near and probably was in that portion of the line of weakness lying under the ocean off the coast of Vancouver Island.

It is known that all quakes have their origin between the surface and a depth of thirty miles. The rate of travel of earth waves through this portion slowly increases as they descend, until they reach the depth of thirty miles; then a sudden increase occurs, which becomes a little greater as the earth's centre is approached. In an illustration, the outer ring, is more properly called the "Rock Mantle." Beneath this a far denser material exists, which extends to the earth's centre, called the "Metal Core."

Between the rock mantle and the metal core there are thought to be areas composed of a molten or plastic substance, and that volcanoes may be their vents during periods of abnormal earth strains. The density of the entire earth is five and a half times that of water, and as the surface rocks are only 2½ to 3½ times denser than water, the metal core is more rigid than steel and is now thought to be composed of iron.

Dr. Hecker, of Berlin, has discovered that the earth's surface rises and falls several inches twice a day, caused by lunar and solar attraction.

The subject of slow movements of the pendulum in relation to certain phenomena will now be briefly discussed:

Apart from the rapid swingings of the pendulum here during the passage of earth waves, the writer has studied the long period swings almost constantly noticeable upon our Victoria instrument. After obtaining a continuous record of these daily changes for the years 1899 and 1900, the results were taken to Cambridge and laid before Sir George Darwin. He was surprised at the great movements shown and the small effect due to the loading action of the tide on the coast. Sir George suggested the recording of observations of a further period of years, and the installation of another pendulum to swing north and south.

This has been done, and several papers bearing on the subject have been published.

The final results have recently been studied by Sir George Darwin, and recently a detailed criticism upon this work has been received from him. He suggests certain changes, and sends special mathematical formulæ for assisting the work, and expresses the hope that these studies will be continued.

The chief feature of this study, which has been completed to December, 1910, was the construction of a curve deduced from the monthly mean position of the East and West horizontal pendulum from January, 1899, to the present time. Under this curve was placed another, giving the number of earthquakes recorded monthly at Victoria during the same period.

The pendulum curve showed a well-defined easterly swing during summer, and a westerly movement in the autumn and winter. Apart from this, a longer period was noticeable throughout the pendulum curve.

From January, 1899, to November, 1900, a steady westerly movement is observed; this was succeeded by an easterly movement, until the summer of 1906, when another, less marked westerly movement occurred, lasting till the winter of 1908, when the pendulum again steadily travelled towards the east to the close of 1910.

By studying the earthquake frequency curve, in conjunction with the pendulum movements, it was found the greatest number of quakes in each year occurred during the westerly pendulum movement. Comparing the two curves from a yearly point of view, we find that a maximum number of quakes occurred in 1899 and 1900, or about the time of the extreme westerly pendulum movement, another maximum of quake frequently occurred in 1906, agreeing with the maximum easterly pendulum swing of that year. The next maximum of annual number of quakes was 1910, also the year of another marked easterly swing of the pendulum.

Through the courtesy of Mr. Thos. R. Stockett, manager, and Mr. Thos. Graham, superintendent, of the Western Fuel Co., Nanaimo, B.C., two horizontal pendulums have been installed at that Company's mine, one on the surface, the other nearly 1,000 feet below. These are read twice a day, gratuitously, and although it is advisable to obtain further observations from them, it may be stated that the results have proved very valuable, especially when studied with the records made by the Victoria instruments.

Thinking there might be some connection between coal mine explosions and earthquakes, or the long period movements of the pendulum, the writer has, through the kind assistance of Mr. Harold T. Nation, of the British Columbia Department of Mines, obtained a list of coal mine explosions that have occurred in America and Europe from 1900 to the present year. This list includes only explosions when five or more human lives were lost.

This list of North America, though probably incomplete, gives a total of 114 explosions and a loss of human life of 3,850 since 1900.

When these were studied month by month with the pendulum movements, it was found they were grouped into almost regular periods, and that in each year the greatest number occurred during the months when the pendulum had reached its extreme

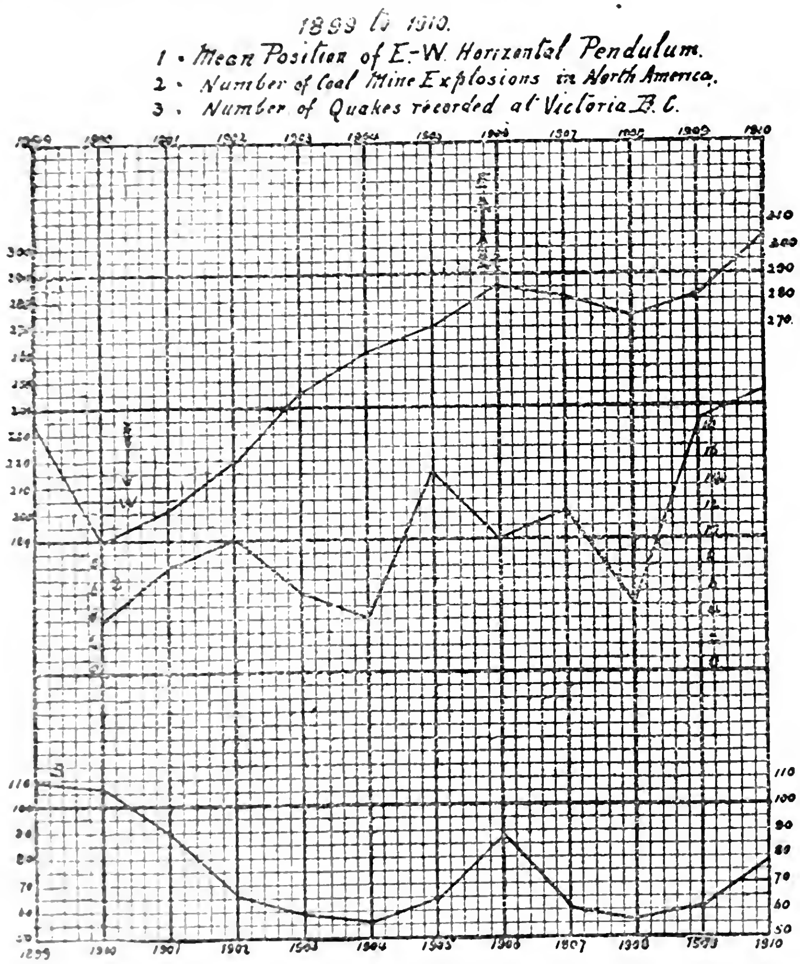
NUMBER OF COAL MINE EXPLOSIONS IN NORTH AMERICA, 1900 TO 1910, IN WHICH 5 OR MORE LIVES WERE LOST.

	Jan.	Feb.	Mar.	Apr.	Ma.	Jn.	Jly.	Aug.	Sep.	Oct.	Nov	Dec	Yr.	No. of lives lost
1900	0	0	1	0	1	0	0	0	0	0	2	0	4	266
1901	0	1	0	1	2	1	0	0	1	2	0	0	8	163
1902	1	0	2	0	2	0	1	1	2	0	1	0	10	505
1903	0	0	0	1	0	2	1	0	0	0	1	1	6	218
1904	2	1	0	0	0	0	0	0	0	0	0	1	4	210
1905	0	3	2	4	0	0	2	0	0	1	2	1	15	282
1906	2	3	1	1	0	0	0	0	0	3	0	0	10	194
1907	3	1	1	0	1	1	0	0	0	0	0	5	12	888
1908	1	1	1	0	0	0	0	0	0	0	1	1	5	281
1909	3	1	2	3	0	1	1	0	0	4	1	3	19	295
1910	0	4	3	2	1	0	0	0	0	1	6	4	21	548
Total	12	15	13	11	7	5	5	1	3	11	14	16	114	3850
%	11	13	11	11	6	4	4	1	3	10	12	14	*9.5	†321

* Average yearly number of explosions.
† Average yearly number of lives lost.

westerly swing. These periods are also the times of greatest seismic frequency.

The foregoing table shows that during the past eleven years the greatest number of explosions (16) occurred in the month of December, while the least number (1) was reported in August.



In the above diagram the mean annual position of the E–W horizontal pendulum is given from 1899 to 1910, and under this is the annual coal mine curve taken from the above table. Beneath this is the annual number of quakes recorded at Victoria.

In comparing these curves it is interesting to note that the year of the fewest mine explosions, viz., 1904, is also the year of the smallest number of quakes; while in 1906, the year of one maximum easterly swing of the pendulum, is also the central year of three of an abnormal number of mine explosions. A marked maximum in the quake frequency also occurs in 1906.

Another year of few mine explosions, viz. 1908, is also one of few quakes, and corresponds with the time of a maximum westerly swing of the pendulum. During the years 1909 and 1910 the pendulum steadily moved eastward, and by the close of the latter it had exceeded its position in 1906. Both the mine explosions and quake curves for these years also indicate a remarkable increase.

Before attempting an explanation of these apparent correspondences, the writer desires to state that he has compared the dates of the 114 explosions under discussion with the dates of all quakes recorded here, and has obtained the following results:—

Twenty-two per cent. occurred upon the day of a quake, 18% upon the day after a quake, and 8% upon the day before a quake. That is, 48% of these mine explosions occurred either on the day or within 24 hours before or after a quake.

Nine European and South American mine explosions were compared in the same manner. The results were: 33% occurred upon the day of a quake, 22% on the day after a quake, and 22% upon the day preceding a quake.

These results, viz. 77%, give an even larger number of explosions occurring either on the day or within 24 hours before or after a quake.

In attempting an explanation of the foregoing correspondences, it is necessary to throw as much light as possible upon the true meaning of the monthly and annual pendulum movements already referred to.

These horizontal pendulums are to a certain extent affected by changes of atmospheric pressure upon the earth's surface, loading of the coast by the ocean tides, and probably by local and more general temperature conditions. Apart from these and doubtless other influences, these pendulums appear to respond to some great and mysterious forces ever active on or within the earth.

The marked relationship between the periods of maximum seismic frequency and the extreme movements of the pendulum suggests the earth is then undergoing abnormal strains and quakes occurring along the lines of weakness in the earth's rock mantle.

In respect to the agreement between the times of mine explosions and quakes, it is suggested that the former are the result of a combination of two or more forces. One of these may be an abnormal escapement of gas into a mine caused by a movement of the rock strata during the passage of earth waves from a severe and comparatively local quake.

Another form of gas dislodgment may occur during those periods of great earth strains, even before a quake or fracture has occurred perhaps in some remote portion of the world; for the surface waves from these quakes do not extend to any great depth, while the longitudinal waves that pass through the denser portion of the interior are small. Another cause of gas escapement, particularly during the winter months, is the rapid movements of our great cyclonic areas of low barometric pressure across the various mining centres. Much valuable information has been given to the mining world upon this subject; but attention is directed to the fact that apart from the gas escapement due to the sudden decrease of air pressure in the mines, there is an enormous load of air removed from the surface, which, when abnormal earth strains prevail, may cause a slight movement of certain rock strata, and even the dislodgment of gas.

The above suggestions refer to abnormal escapements of gas into mines. As regards the actual forms of ignition that cause these explosions, it may be that apart from the various sources of danger so ably discussed by numerous authorities, many of these disasters, which occur particularly during the winter months, are caused by certain electrical conditions prevailing in the mines and rock strata.

We are aware from time to time of "earth currents," so strong indeed as to interfere with our telegraphic systems. The aurora and magnetic storms are also evidences of this great force.

It is possible these conditions may reach a maximum of intensity during certain periods of great terrestrial unrest, when (as for instance) a fall of rock or coal oppositely charged from what it strikes, might cause sufficient spark to bring about an explosion.

In conclusion it is urged that this subject be further investigated upon broad and comprehensive lines, and later it may be possible to determine when abnormal and dangerous conditions might prevail in certain districts.

THE TYPES AND MODES OF OCCURRENCE OF ASBESTOS IN THE UNITED STATES.[1]

By J. S. DILLER, U.S. Geological Survey, Washington, D.C.

(Annual Meeting, Quebec, 1911.)

INTRODUCTION.

The United States has for many years led all other countries in the manufacture of merchantable products into which asbestos largely enters, but in the mining of asbestos it has not until recently attained any importance, and even now produces only about one-twentieth the yield of Canada; but Canada's production constitutes so large a part of the world's total annual output that even a five per cent. contribution from another country is well worthy of mention.

The mining of asbestos in the United States is reported as early as 1880. This asbestos of the amphibole variety and its mining, with a variable annual production, has since continued. With the production of chrysotile, a year ago, a more important phase of the industry was however initiated. The production has been increased to over 3,000 tons, and the outlook for the future is promising.

As at present known there are in the United States six asbestos localities of more or less interest either to the asbestos industry or to science. These are in the vicinity of Lowell, Vermont; Casper, Wyoming; Grand Canyon, Arizona; Sall Mountain, Georgia; Kamiah, Idaho; and Bedford, Virginia. At the localities in respectively Vermont, Wyoming, and Arizona, the

[1]Published by permission of the Director of the United States Geological Survey.

asbestos is chrysotile, and at the remaining three, in Georgia, Idaho and Virginia, it is amphibole.[1] Practically all the asbestos produced in the United States in 1909 came from Vermont and Georgia.

The writer has visited all the above mentioned localities for the special purpose of noting production, but the stay of only a few hours or days at each locality gave no opportunity for detailed study. However, the great interest in asbestos is a sufficient apology it is hoped for the submission of a general survey of the field, noting specially asbestos types and modes of occurrence in the United States.

TYPES OF ASBESTOS.

There are three types of asbestos fibre; cross fibre, slip fibre, and mass fibre. Cross fibre asbestos occurs in veins, and the fibres if not disturbed lie transversely from wall to wall. Slip fibre occurs in slipping planes, and the direction of the parallel fibres in the plane indicates the direction of the slipping. It is often associated with slickensides, and may be widely distributed throughout the rock in the planes of readjustment to changing stress. Occasionally, the slipping is extensive and the shear zone or fault plane has a mass of slip fibre a foot or more in thickness and many feet in length and breadth, forming a definite vein deposit of considerable size. Mass fibre occurs in fibrous bundles or groups and the fibre may be parallel or divergent, often radial. It is strongly contrasted with the cross fibre and the slip fibre types in that it does not occur in veins but forms the whole mass of the rock in which it is developed.

Asbestos of the cross fibre type is almost always chrysotile, but rarely it is anthophyllite. Asbestos of the slip fibre type is sometimes chrysotile, but more commonly amphibole. Asbestos of the mass fibre type, as far as known, is always anthophyllite.

MODES OF OCCURRENCE.

By modes of occurrence is meant the environment of the asbestos deposit, referring especially to its relation to the rocks with which it is genetically associated.

[1]The term amphibole is used in its broad sense to include anthophyllite.

There are four modes of occurrence of asbestos in the United States.

The first mode is as cross fibre veins of chrysotile in serpentine derived from peridotite, a deep-seated igneous rock, as near Lowell, Vermont, and Casper, Wyoming. As far as known it is much the most important mode of occurrence and is well illustrated at the Thetford Mines in Canada.

A second mode is as cross fibre veins of chrysotile with serpentine in limestone. Its most important illustration is in the Grand Canyon of the Colorado in Arizona.

The third mode is its occurrence as mass fibre amphibole (anthophyllite) composing stocks and dykes of fibrous amphibolite. and is well illustrated in the deposits worked for many years at Sall Mountain, Georgia. Asbestos of this mode has recently been opened up and attained some importance at Kamiah, Idaho.

It is of interest to note also a closely related mode of mass fibre amphibole (tremolite-asbestos) which in the form of schist is interbedded with limestone in the vicinity of Gouverneur, N.Y. Much of the fibrous amphibole has been altered to talc and is the material so extensively mined as talc in that region.

The fourth mode is as slip fibre veins in rocks which for the most part belong to cortlandite and pyroxenite which locally pass into peridotite, as at Bedford and Rocky Mount, Virginia. An example of each of these modes of occurrence in the United States will be briefly described.

Commercial asbestos has been found in the first and third modes of occurrence only. Attempts have been made, although not yet successful, in mining asbestos of the second and fourth modes of occurrence.

First Mode of Occurrence—Asbestos of Casper Region, Wyoming.

Distribution.—In the front range of the Rocky Mountains near Casper, Wyoming, there are two distinct localities of asbestos one on Casper Mountain, 8 miles directly south of Casper, and the other on Smith Creek about 20 miles southeast of Casper. The Casper Mountain area embraces approximately 4½ square miles and the Smith Creek area nearly 7 square miles. Both areas have their greatest extent in a line running a few degrees north of east, and are characterized by the same rocks among which serpentine, diorite, and granite are perhaps the most important.

Structure.—The rocks of the asbestos areas, as far as observed, are wholly igneous. They lie unconformably beneath the Cambrian sandstone and belong to the Archean. The Smith Creek and Casper Mountain areas are due to anticlines which bring the deep-seated altered rocks to the surface. The two areas are separated by a broad syncline which contains a great thickness of Palæozoic and Mesozoic sediments. These sediments have all been deposited since the asbestos was formed. The general geologic features of the region have been worked out and published[1] by N. H. Darton, of the U.S. Geological Survey.

Rocks of the asbestos areas.—The rocks of the asbestos areas are hornblende schist, diorite, granite and serpentine. The black hornblende schist is a well defined medium-grained schist in which hornblende is somewhat more abundant than the altered feldspar and quartz. The diorite differs from the hornblende schist generally in being finer grained and without definite schistose structure. It is often compact with the habit of greenstone.

Granite is perhaps the most distinctive rock of the areas. It is medium to coarse-grained and generally red owing to the colour of the abundant feldspar. Much of it is composed of quartz and feldspar with only a trace of hornblende or other ferromagnesian silicates. The structure though generally even granular is often graphic and the rock passes into pegmatite and appears in the form of more or less distinct dykes. The granite is generally regarded as the principal rock in the great Archean mass of the Laramie Range and older than the diorite and serpentine. This may well be for the main body, but in the asbestos areas, especially in the divide between Smith Creek and Deer Creek, the granite locally appears as large dykes and sends tongues into the adjacent serpentine.

Serpentine being the source of the asbestos is by far the most important rock of the area. It occurs in belts which, at least in the Smith Creek area where their distribution has been noted most fully, extend northwest and southeast. This is true

[1] U.S. Geological Survey, Prof. Paper No. 32, Pl. XXXV.

both of the mass which is now being worked at the west end of the area as well as the one farther east extending through the property of the International Asbestos Mills and Power Company. The western belt is about 1500 feet long and from 150 to 300 feet wide. In general the trend of these belts is toward the asbestos area of Casper Mountain, and suggests the connection of the two areas beneath the syncline of sedimentary rocks that lies between them.

The most common type of serpentine is bluish and impure, but the more typical form is that which is associated with asbestos. It is generally very much crushed and sheared. The serpentine where examined contained no remnants of the original rock from which it was derived. Its microscopical structure, however, clearly indicates that the original rock was composed almost wholly of olivine. It was not only a peridotite but practically a dunite.

The rocks of the asbestos areas, ranging from granite to peridotite with a number of intermediate forms, resulted apparently from the differentiation of a single magma of which the asbestos is one of the final products.

Asbestos.—Cross fibre veins.—The asbestos of the Casper Mountain region is almost wholly chrysotile. In colour it varies from pale green to colourless on the one hand and to yellowish bronze on the other, and occurs in the form of cross fibre veins in serpentine. Veins were observed at a number of places with fibre over an inch in length. In the same vicinity there are usually found great numbers of small parallel cross fibre veins ranging in thickness from that of paper up to three-fourths of an inch. Veins from one-fourth to one-eighth of an inch in thickness are most common. Some of the veins cut others, indicating that all of the veins of chrysotile were not formed at the same time. In these parallel groups, the larger the veins the greater the distance between them. The waxy lustred serpentine between the veins varies in colour from greenish yellow to gray. Grains of magnetite are common in the serpentine, and occasionally with a little asbestos it forms dark lustrous veins up to one-fourth of an inch in thickness; but in general the asbestos veins of the Casper region are free from magnetite and in that respect appear to have an advantage over the asbestos veins of Vermont and Canada. The belts of such parallel veins may be from 4 to 10 feet wide. A number of such belts, rich in asbestos veins, occur within the serpentine. Between these belts the serpentine is either barren or contains only a few small veins of asbestos.

As in other asbestos fields, the veins of cross fibre are traversed by parallel partings, which cut the fibre to shorter lengths and greatly reduce its grade; but such partings are not more abundant in the cross fibre veins of the Casper region than elsewhere.

Slip fibre.—There is much slip fibre in the sheared portions of serpentine, and although some of it is brittle and lacks tensile strength, most of it is of good quality. The asbestos veins in places are not only puckered and crumpled but crushed and sheared so that the cross fibre appears to pass into slip fibre as at East Broughton, Canada. These rocks evidently have been much disturbed and sheared since some of the earlier asbestos veins were formed. Much of the slip fibre may be younger than the cross fibre.

Relation of asbestos to granite.—Although the cross fibre veins of chrysotile are always in serpentine the localities in which they are most abundant are generally near the contact between serpentine and granite. This is especially true at the McConnel shaft and the Rainbow in the Casper Mountain area, as well as at several points in the International and the Wyoming Consolidated properties on Smith Creek, and the larger veins are for the most part approximately parallel to the contact as though the granite were a factor in their development.

SECOND MODE OF OCCURRENCE—ASBESTOS OF THE GRAND CANYON, ARIZONA.

Preface.—The asbestos of the Grand Canyon of Arizona illustrates the second mode of occurrence of asbestos, that is, its occurrence with serpentine in limestone.[1] The serpentine, like the limestone in which it occurs, is derived from material of sedimentary origin, and as to its original source is therefore in strong contrast with the serpentine derived from peridotite.

[1] A somewhat similar case is described by Merrill as occurring at Montville, N.J. Proc. U.S. National Museum, 1888, p. 105.

Distribution.—The asbestos belt of Arizona is a long narrow strip, a definite geological horizon among the Algonkian strata in the depths of the Grand Canyon of the Colorado, about 4,000 feet below its rim and in places over a thousand feet above the river. It has been studied at two localities in the canyon; one beneath Grand View,[1] where the serpentine-asbestos belt is exposed for nearly 2 miles with a width of only a few feet, and the other locality 30 miles farther west in the canyon beneath Bass' camp,[2] where the same belt has a length of about three-fourths of a mile. According to Mr. Noble the same asbestos horizon outcrops for several miles in the canyon west of Powells Plateau; but owing to its inaccessibility the locality has not yet been examined.

Structure.—The structure of the asbestos belt is monoclinal. The strata in it are part of a thick series of Algonkian strata which generally dip to the north or northeast from 10 to 20 degrees and are traversed by occasional normal faults, generally of small displacement. These rocks form part of the north wall of the great gorge of the Colorado, where they are separated from both the overlying Cambrian and the underlying Archean by conspicuous unconformities. The strata although deep-seated and of great age are as a body not crushed, fractured or metamorphosed as are those in which asbestos of the first mode occurs, and this has an important significance concerning the origin of the asbestos veins.

Rocks and their relations.—The rocks with which the asbestos is associated are given in the following section[3] below the great sill of diabase in Asbestos (Hakataia) Canyon.

DIABASE.

Layer of green serpentine.	2 ft.
Pure, white, crystalline limestone.	1 ft. 6 in.
White, crystalline limestone with bands and nodules of serpentine	2 ft.
Serpentinous, nodular and banded layer carrying veins of asbestos	1 ft.

[1]J. Hyde Pratt, U.S. Geol. Survey Mineral Resources, 1904, p. 17.
[2]L. F. Noble, Am. Jour. of Sci., vol. XXIV, June, 1910, pp. 520–522, and personal letter dated June 21, 1910.
[3]Noble, in Am. Jour. Sci., vol. XXXIX, p. 520.

Banded, crystalline limestone with bands and nodules of serpentine	10 ft.
Nodular cherty limestone	4 ft.
Soft blue slate	5 ft.

The asbestos horizon below the diabase is not absolutely constant but may lie, according to Noble, anywhere from 3 to 15 feet below the contact.

Above the upper contact of the diabase the limestone contains some serpentine and small veins of asbestos rather widely distributed; but on the whole it appears to be much less abundant and persistent than that below the diabase.

"The serpentine[1] and asbestos occur in the limestones only where these strata are invaded by the diabase sill; where the diabase lies between shales there is no development of these minerals within the invaded strata. In no place in the area are they developed within the diabase itself. It is therefore clear that they are a contact metamorphic phenomenon conditioned by the invasion of the limestones by the diabase. It seems probable, as suggested by Diller (a, p. 72), that the serpentine which enclosed the veins of asbestos is derived from some mineral in the limestones and not from the diabase. The limestones themselves are magnesian, and locally siliceous in the form of chert bands and nodules. In another part of the area the conversion of the shales to jaspers where they are in contact with the diabase is evidence that the fumarolic action accompanying the injection of diabasic magma was manifested by aqueous and probably siliceous emanations and was fairly intense. It seems possible that the operation of the fumarolic action upon the elements already present in the magnesian limestones might have been sufficient to convert the more siliceous portions into serpentine. The occurrence of the asbestos in veins that cut both the nodules of serpentine and the limestones is evidence that the formation of the cross fibre asbestos was itself a somewhat later phenomenon."

Asbestos.—The serpentinous layer that carries the asbestos is usually from 12 to 14 inches in thickness and the general trend of the asbestos veins within it is parallel to the bedding of the limestone. Locally the asbestos fibre is 4 inches in length from side to side of the vein, but generally the veins do not exceed

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[1]Noble, in Am. Jour. Sci., vol. XXXIX, pp. 521–522.

2½ inches and frequently appear as a series of small parallel veins. The larger veins are remarkable for their continuity. According to Pratt,[1] under Grand View, where the outcrop of the serpentine-asbestos layer is sometimes as much as 18 and often 24 inches in thickness, there may be in it 2 or 3 large parallel veins of asbestos that continue for 150 feet. Within this thin layer containing the asbestos, cross fibre veins over an inch in width are common. The width of the veins within this horizon at some localities varies greatly from place to place, so that a 3-inch vein in one locality may be represented by a zone of innumerable small veins in another, but the actual continuity of the zone that carries the asbestos, according to Noble, is rarely broken.

The asbestos veins have but few partings, and they are generally of chalcedonic quartz with rough borders instead of the smooth sharp lines like those which generally mark the sides of the vein. Very little if any magnetite is present in the veins. The asbestos is generally a beautiful golden yellow though sometimes shading to pale green. It is finely fibrous, smooth, silky, and of great tensile strength, so that it compares favourably with the crude asbestos from any other country.

Locally as much as 40 per cent of the 12-inch layer may be No. 1 and 2 crude with 10 per cent of lower grades; but in general the thin layer would probably not average more than 15 per cent of all grades.

The eastern area under Grand View has been most extensively prospected. A few years ago the Hance Asbestos Company opened a number of cuts along the outcrops and ran tunnels down the dip to the extent, in some cases, of 75 feet.

The large proportion of crude to other grades in this Grand Canyon deposit is remarkable. Ordinarily such a deposit could be profitably mined; but considering the narrow limits of the asbestos horizon taken in connection with its attitude and the difficulties of transportation in getting the asbestos across the river and out of the canyon to the railway appear to render successful mining very problematical, excepting in a small way using donkeys for transportation. In any case it would have to be on a limited scale only and for high-grade material.

[1]U.S. Geol. Survey Mineral Resources, 1904, Asbestos, p. 18.

Whatever part the asbestos of the Grand Canyon may play in the asbestos industry, it will ever be recognized as one of the most exceptional and interesting deposits of asbestos yet discovered.

The entire absence of rock crushing and the remarkable continuity of the asbestos veins approximately in the plane of stratification clearly indicate that the veins of asbestos were not deposited in open fissures but by replacement of serpentine in plane of least strength somewhat later than the development of the serpentine itself.

Here, too, we have convincing evidence of the development of asbestos by igneous intrusion. We may therefore the more readily accord to the granite dykes in Canada and elsewhere a decided influence in the formation of the asbestos near their contacts.

THIRD MODE OF OCCURRENCE—ASBESTOS OF KAMIAH, IDAHO.

Preface.—The third mode of occurrence of asbestos is as mass fibre in dykes or lenticular bodies of amphibolite, and good examples of this mode occur near Kamiah, Idaho, and Sall Mountain, Georgia.

The Idaho locality is about 14 miles southeast of Kamiah, where the amphibolite forms about half a dozen ledges within a few square miles. The largest of these ledges having a lenticular shape is about 200 feet in length, 40 feet in width, and 35 feet in eight above the ground. The ledges are apparently intruded in mica schist, but deep prospecting has discovered the bottom of some of these masses and they must not be expected to extend down great distances. They will in some cases at least probably pinch out before reaching a depth as great as the length of the outcrop on the surface. But as there are a number of openings and probably other masses not yet discovered a large quantity of material is available. The term "mass fibre" is used to indicate that the whole mass is fibrous and that the fibre is neither cross fibre nor slip fibre, both of which are essentially vein deposits. The fibrous mineral, according to Merrill[1] who studied the Sall

[1] A brief account including chemical analyses of the asbestos of Sall Mountain and other localities in Georgia was published by George P. Merrill, in the Proceedings of the U.S. National Museum, Vol. XVIII, 1895, pp. 282–291.

Mountain rocks, is anthophyllite. The fibres are arranged in small bundles ¼ to ¾ of an inch in length. The bundles generally lie in all directions through the rock but are often arranged in radial groups so as to form rosettes on cross fractures. The rosettes are sometimes 4 inches in diameter with radial fibres of dull to vitreous lustre and many cross fractures. The fibres are brittle and readily break into short lengths and split into fine threads that are polygonal in cross section. None of the material is of spinning grade, and its short mill fibre of low tensile strength renders it much less valuable than all but the lowest grades of chrysotile.

At present all the rock quarried is hauled in waggons to Kamiah and transported by rail to Spokane, where the Spokane Asbestos Firebrick Company saws and grinds it for various purposes. As already stated, asbestos of the mass fibre and amphibole type has been mined more or less successfully for a number of years at Sall Mountain, Georgia.

Fourth Mode of Occurrence—Asbestos of Bedford, Virginia.

The fourth mode of occurrence of asbestos is as slip fibre veins in rocks of variable composition, though perhaps generally hornblendic. The best illustration yet observed by the writer of this mode in the United States is 12 miles south of Bedford City, Virginia, where there are two outcrops of a few acres each. The asbestos is of the amphibole variety. The prevailing rock of the area is composed of hornblende and olivine. In some cases it is pyroxene and olivine, and in other cases almost wholly olivine. For the most part the rock is closely related to cortlandite; but in some places it is peridotite and locally may be pyroxenite. These different rocks all appear to be differentiation products from one magma. In nearly all cases the rock has numerous acicular crystals and fibrous bundles of anthophyllite. The same mineral rarely forms cross fibre veins.

This rock complex is cut by occasional planes of shearing along which there has been developed vein-like masses of slip fibre that lie in the plane parallel to the direction of slipping.

These masses of slip fibre attracted the attention of prospectors for asbestos and are the parts that have been mined out. The veins of which there are several in the same vicinity strike approximately N.W. and S.E. with dip to the S.W. A vein 18 inches in thickness has been followed along the strike for 30 feet, and down the dip by 2 inclines for perhaps 50 feet. These masses of slip fibre are very irregular, and as far as known are of so small extent as to furnish a very unreliable basis for mining operations such as were inaugurated a few years ago and failed, not only on account of the low grade of the fibre but on account of the limited quantity available.

SUMMARY.

Aside from the various minerals serpentine, amphibole, anthophyllite and crocidolite, all of which have asbestiform varieties, there are three types of asbestos fibres distinguished by the manner of grouping as cross fibre, slip fibre and mass fibre, and all are of commercial importance but of different degrees decreasing in the order named.

Cross fibre forms veins, and the fibres though parallel to one another are perpendicular to the plane of the vein and directly traverse it from wall to wall. Chrysotile generally appears in this type and anthophyllite rarely.

Slip fibre forms veins on slip planes and the fibres are parallel not only to one another but to the direction of slipping. Chrysotile, amphibole and anthophyllite appear to be of this type.

Mass fibre is strongly contrasted with cross fibre and slip fibre in that it is not a vein formation but constitutes large bodies of rocks. The fibres are grouped in bundles or bunches and may be parallel or divergent. The groups of fibres lay in all directions in the rock; but in some cases they are arranged parallel by earth movements and the rock becomes schistose. Anthophyllite only is known in this type, and although of much lower grade than chrysotile the yield is large, for ordinarily 90 per cent of all that is removed from the quarry is bagged in the mill.

Using the phrase "mode of occurrence" to refer especially to the genetic relation of the deposit to its environment, there are four modes of occurrence of asbestos in the United States.

The first mode is as cross fibre veins in serpentine derived from peridotite. It is the mode of the deposits near Lowell, Vt., and Casper, Wyoming, as well as in the productive mines at Thetford, Canada.

The serpentine of the Casper Mountain region where purest is clearly derived from olivine, and the asbestos where most abundant is associated with the purest serpentine.

Asbestos veins are in general most abundant in the vicinity of masses of granite, suggesting that the intrusion of the granite was a factor in the development of the asbestos.

The second mode of occurrence of asbestos is as cross fibre veins developed in limestone by the contact metamorphism of an adjacent intrusive rock. A striking example of this mode is exposed in the Grand Canyon of the Colorado wherever a certain magnesian limestone of Algonkian age comes in contact with a thick sill of diabase. Certain portions of the limestone were converted into serpentine, and somewhat later the serpentine became traversed by veins of asbestos approximately parallel to the bedding of the limestone. Although the asbestos belt is very narrow the quantitative proportion of Nos. 1 and 2 crude asbestos of excellent quality to that of the lower grades is very large. Nevertheless, the serpentine-asbestos belt is so narrow, and in the Canyon the difficulties of deep mining and transportation are so great, that the successful exploitation of this asbestos is very problematical unless it be in a small way by the removal of the high-grade material from along the outcrops.

The third mode of occurrence is as lenticular masses or dykes of mass fibre amphibolite, such as has been mined for a number of years at Sall Mountain, Georgia, and has lately been opened up at Kamiah, Idaho. This material, especially when weathered, is easily mined and pulverized. Being brittle it breaks into short lengths and yields but one grade. However, so large a proportion of the whole mass (90 per cent.) turns out as fibre that though of low grade quality mining operations have continued for years.

The fourth mode of occurrence of asbestos is in veins of slip fibre traversing rocks closely related to cortlandite, pyroxenite and peridotite and is illustrated by deposits near Bedford, Va. The rocks are much sheared and are locally converted into amphibolite schist. The asbestos is developed most prominently on the fault planes where masses of amphibole slip fibre of considerable size have attracted the attention of miners but have not yet yielded profitable mines.

Some slip fibre is found in nearly all masses of serpentine. Locally it is soft and strong and appears to be chrysotile, but much of it being amphibole is harsh and brittle and of much lower grade than chrysotile.

THE ASBESTOS DEPOSITS OF THE NEW ENGLAND STATES.

By C. H. RICHARDSON, Syracuse University, Syracuse, N.Y.

(Annual Meeting, Quebec, 1911.)

Dr. F. W. Clarke[1] in his data of Geochemistry says that the mineral serpentine is optically monoclinic and that no true crystals are known.

In composition it is a hydrous silicate of magnesium. In formula, $2H_2O$, $3MgO$, $2SiO_2$. The various wet reactions by which hydrous aluminum silicates are prepared in the chemical laboratory throw but little, if any, light on the interpretation of serpentine.

The mineral appears to be in nature only of secondary origin. It is derived from the ferro-magnesian minerals olivine and chondrodite, the amphiboles hornblende and actinolite, the pyroxenes enstatite, bronzite and diopside, and possibly from other magnesian minerals.

According to L. Finckh[2] large masses of gabbro may be transformed into serpentine. According to G. H. Williams[3], peridotite undergoes this metamorphism. According to J. B. Jaquet[4], amphibolite may undergo the same change. G. F. Becker[5] in a monograph of the United States Geological Survey and J. H. Teall[6] in his works on British Petrography have ably

[1] F. W. Clarke, Data of Geochemistry, p. 348. 1908.

[2] L. Finckh, Zeitcshr. Deutsch. Geol. Gessell, Vol. 50, p. 108. 1898.

[3] G. H. Williams, Am. Jour. Sci., 3rd Ser., Vol. 34, p. 137. 1887.

[4] J. B. Jaquet, Rec. Geol. Survey, N. S. W., Vol. 5, p. 18. 1905.

[5] G. F. Becker, Mon. U. S. G. S., Vol. 13, p. 108.

[6] J. H. Teall, British Petrography.

discussed the origin of large masses of serpentine derived from the metamorphism of the ultra-basic rocks rich in olivine.

F. W. Clarke,[1] again, says that when distinctively magnesian minerals undergo metamorphism, which happens chiefly in the belt of weathering, the product is likely to be either talc or serpentine. A typical production of serpentine is from rocks containing olivine. The reaction may be expressed as follows:

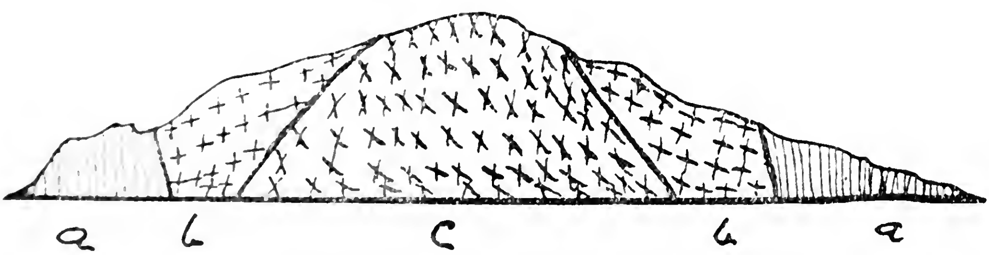
$$2Mg_2, SiO_4 + 2H_2O + CO_2 = 2H_2O, 3MgO, 2SiO_2 + MgCO_3.$$

The ratio of the magnesium to the iron varies from 16 : 1 to 2 : 1. With the larger iron content the carbonate of magnesium and iron may form. Such a ferruginous magnesite, often rich in silica, is found at the Red Rocks, in Troy. The red colouration, due to the oxidation of the iron, appears very nounced upon the surface.

F. W. Clarke also gives, on the same page as cited above, the following equation for serpentine derived fiom the pyroxene diopside:

$$3MgCaSi_2O_6 + 3CO_2 + 2H_2O = Mg_3H_4Si_2O_9 + 3CaCO_3 + 4SiO_2.$$

The silicious magnesite between the village of North Troy and the Red Rocks appears to have been formed through the hydrous metamorphism of pyroxene, rather than peridotite.



a—Schists. *b*—Pyroxenite. *c*—Peridolite. Troy, Vt.

B. K. Emerson[2] ascribes the origin of the serpentines of Massachusetts to the hydrous metamorphism of amphibolites. The serpentines in limestones and dolomites, as in Westchester and Warren counties, N.Y., result, not from the metamorphism of batholiths of peridotite or pyroxenite, but from the secondary changes in the metamorphic magnesian silicates in those limestones and dolomites.

[1] F. W. Clarke, Data of Geochemistry, p. 519. 1908.
[2] B. K. Emerson, Mon. U. S. G. S., Vol. 29, p. 114, 1898.

The Vermont serpentines could not have been formed from this type of rocks, for limestones and dolomites are nowhere associated with the peridotite in the eastern half of the State. The nearest approach to such carbonates is manifested in the ferruginous and silicious magnesite mentioned above.

Prof. V. F. Marsters[1] in his Vermont Reports, discusses the Amphibolites of Belvidere Mt. They are practically confined to the uppermost 1,000 feet of the mountain and extend as far north as Hazen's Notch. He also cites two small exposures of the same rock at the lower edge of the serpentine, now worked by the Lowell Lumber and Asbestos Co., at Chrysotile.

The Amphibolites of Marsters seem to be largely confined to the periphery of the serpentine. They are the rocks that flank the serpentine on the southwest and northeast sides of Belvidere Mt. These rocks consist essentially of dark green hornblende, which at the contact zone of the serpentine is highly garnetiferous. His discussion of the serpentine is practically confined to the single area of Belvidere Mt.

According to Prof. J. F. Kemp[2], the serpentine forms at Belvidere Mt. A projecting buttress, and the mountain crest rise 2,000 feet above the serpentine. To the north of the serpentine there is a precipitous wall of hornblende schist, which a fault, strike N. 15 W., brings abruptly against the serpentine.

Marsters also states that no sharp and well defined contact can be observed between the amphibolite borders and the serpentine. This view is confirmed by the careful examination of many thin sections. Samples taken by Marsters within a few feet of the amphibolite showed amphibolite surrounded by a felty mass of serpentine. He therefore concludes that the amphibolites have slowly altered to serpentine.

Mr. J. A. Dresser[3], of the Canadian Geological Survey, has assigned a different origin to the serpentines of Quebec, viz., the hydrous metamorphism of the ultra-basic rock peridotite rich in olivine.

[1] V. F. Marsters, Bulletin of the Geol. Soc., Vol. 16, pp. 417–444, and 4th Rep. Vermont Geologist, pp. 86–102.

[2] J. F. Kemp, Min. Resources U. S., 1900, pp. 6–12.

[3] J. A. Dresser, Min. Res. of the Serpentine Belt of Southern Quebec, Journal Can. Min. Inst., Vol. 13, 1909.
Annual Rep. Can. Geol. Survey, 1909.

In arriving at my own conclusions, as published in the 7th annual report of the Vermont State Geologist,[1] I am greatly indebted to Mr. Dresser, and thus to the Canadian Geological Survey, for his companionship and timely suggestions, both in northern Vermont and in the province of Quebec.

GEOLOGY.

The serpentine belt, in its southern extension into Vermont, comprises two long and narrow bands flanking the broad U-shaped Missisquoi valley, both upon the east and the west. In Some instances, as at Lowell, Vermont, the bed of the river is in the serpentine.

The terranes cut by the ultra-basic peridotite are highly folded and faulted gneisses, schists, slates and sandstones, in part pre-Cambrian and in part Cambrian. The intrusives are peridotite, pyroxenite, gabbro, gabbro-diorite, diabase and porphyrite.

The term peridotite, as here applied, embraces a series of rocks sometimes granitoid in texture, occasionally porphyritic, but always dark, heavy and basic. The area extends some 30 miles south of the International boundary up the Missisquoi valley into Eden. There are two distinct belts of the serpentine, probably of different periods of intrusion, but possibly of contemporaneous origin and connected with each other at lower depths than the erosion has been effected in the valley. The first may be catalogued the Belvidere area; the second, the Lowell area. The former is in general on the west side of the valley and the latter on the east.

The Belvidere seems fairly continuous to Round Mountain area in Lowell. The eastern belt reaches its maximum development in Lowell. It is fairly continuous to the Canadian border. The margins of the belts are often steatite with serpentine "mashed" and sheared forming the centre. The whole is cut by a diabase of later origin. This phenomena can be observed at North Troy in the western belt, near the village and in the eastern belt about one mile east of the same village.

The order of solidification from a basic magma in decreasing basicity would be:

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[1] C. H. Richardson, Rep. Vt. State Geol., pp. 315–330. 1909–10.

1. Chromite and magnetite. 2. Peridotite. 3. Pyroxenite. 4. Diabase.

The granites and aplites, the more acidic rocks, are not found in Vermont in association with the peridotites.

Serpentine.—The peridotite is the parent source of the serpentine. Serpentinization must take place before crystals of chrysotile can appear. The presence of serpentine does not imply that commercial asbestos is obtainable. The peridotite is not everywhere equally pure; but where it is richest in olivine there the purest serpentine is found.

The pure peridotite in the process of crystallization may lose its iron and a part of its silica. Olivine is an anhydrous mineral. The serpentine is hydrous. In the process of serpentinization the new mineral or rock mass has taken up water to the amount of 12 to 14%. The resulting serpentine is softer than the parent rock. It can easily be distinguished from the fresh peridotite. In many localities the alteration is incomplete, and therefore all stages of transition exist between the holocrystalline peridotite and the pure massive serpentine. Even in the same mine there are hard masses of rock essentially olivine, and in close proximity to these masses, areas of complete serpentinization. For the former rock the author, with some hesitancy, would propose the name olivinite.

In the process of alteration, fracturing is necessary. This process is not confined to one cause alone.

1st. In the cooling of the original peridotite magma, the normal shrinkage of volume would necessitate fracturing. Along these planes serpentinization proceeds into the wall rock.

2nd. Fractures are produced by the necessary expansion due to serpentinization. The greater the mashing, shearing, fissuring and fracturing, the more complete the serpentinization seems to be.

3rd. The dynamic force, as manifested in mountain building, is sufficient to induce fractures. It is most apparent where the intrusives are in contact with sediments, for here would be natural planes of yielding.

4th. The casting off of concentric shells from the more or less rectangular blocks formed in the cooling of the magma favour serpentinization.

Fracturing, therefore, by whatever force, plays the rôle of both cause and effect.

WATER OF CRYSTALLIZATION.

In the process of transition from peridotite to serpentine, water is essential. Its source may not be definitely known. There are two sources that appear to play some part in the process.

1st. The meteoric waters that circulate so freely amongst the rocks. Where springs and brooklets appear in the serpentine, there serpentinization is the greatest. Some of the longest asbestos fibres have been found in these channels.

2nd. The introduction of either acid or basic intrusives would bring in magmatic waters. There are at least two periods of intrusion: 1st, the peridotite itself; 2nd, the later introduction of the diabase.

The pyroxenites in the Vermont belt metamorphose into talc and steatite. They form the higher and the marginal portions of the belt. The peridotite forms the central and lower portions, and are best observed where erosion has reached its maximum.

ASBESTOS.

Mineralogically asbestos is a general term. Pliny used the term for the fibrous members of the amphibole family, as tremolite, actinolite and crocidolite. Dana uses the term also for the delicately fibrous and silky chrysotile.

Commercially asbestos includes both the fibrous amphiboles and serpentines. The asbestos of Mt. Holly, Vt., is delicately fibrous, white to greenish white tremolite. The asbestos of Eden and Lowell is mostly chrysotile. A little actinolite is found at the New England mine on the south side of Belvidere Mt., but the asbestos of the Lowell Lumber and Asbestos Co. at Chrysotile, Vt., is chrysotile. The amphibole varieties carry from 1 to 2% of water, while the latter carries from 12 to 14% of the water of crystallization. The true asbestos—serpentine, variety chrysotile—is silky or silky-metallic in lustre. In colour it ranges through greenish white, green, olive green to brown. In texture it is delicately fibrous, flexible and tough.

Quarrying at the Chrysotile Asbestos Mines, Chrysotile, Vermont, U.S.A.

Asbestos Fiberizing Plant No. 1 at the Plant of the Lowell [illegible] Asbestos Company, Chrysotile, Vermont, U.S.A.

Varieties of Fibre.—1st. The cross-fibre, which is of the greatest commercial importance, occurs in distinct veins and extends from wall to wall of the serpentine. The centre of the fibre is marked by a film of magnetite or chromite, from which the chrysotile grows exogenously into the walls of the serpentine. Tape measurements have proven in several cases two-thirds serpentine and one-third fibre. These fibres vary from a fraction of an inch to two inches in length.

2nd. The Slip-fibre. This occurs parallel with the fracture planes produced by the crushing and shearing of the rocks in the process of mountain building. Such sheared or shaley serpentine often carries more fibre than the cross-fibre rock; but it is not not of so great commercial significance.

3rd. Mass-fibre. As the name implies it does not occur in veins, but in masses, with the absence, or rare presence, of other forms of fibre in the rock.

4th. Shear-fibre. The rocks have been sheared after the cross-fibre was formed. It lies parallel with the fracture planes, but orientation occurred after the development of the fibre. Such shear-fibre is of equal strength, fineness and flexibility with the best cross-fibre. The author has found at Chrysotile samples of this fibre six inches in length.

ORIGIN.

Chrysotile represents the molecular rearrangement or crystallization of the serpentine in forms most delicately fibrous. The fracturing of the original peridotite by cooling, by expansion due to serpentinization, by the process of mountain building, by throwing off economic shells from rectangular blocks, or by whatsoever cause the parent rock may be broken, is necessary that serpentinization may ensue. The crystallization of the serpentine in delicately silky fibres gives rise to chrysotile. It is the amorphous serpentine of the side walls that suffers this change. The presence of the film of magnetite now marks the line of fracture. The growth is outward from this band of magnetite or chromite into the walls of the serpentine. Its growth is exogenous (outward) rather than endogenous (inward), as is manifested by the filling of a fissure from the walls inward. The author of this paper, together with Mr. Dresser, saw at the property of the Lowell Lumber and Asbestos Co., in 1909, the film of magnetite in the centre of the asbestos vein, the asbestos vein ½-inch in width, the serpentine band 1½ inches wide on either side of the asbestos vein, and beyond these bands of serpentine, the peridotite, essentially olivine.

The crystallization is always proportionate to the serpentinization. A well serpentinized rock should yield 15% of asbestos fibre. The process of crystallization demands: 1st, moisture, derived either from meteoric or magmatic waters, or both; 2nd, heat, from overlying sedimentaries, regional disturbance or the introduction of intrusives.

CONCLUSIONS BASED UPON THE STUDY OF THE GEOLOGICAL FORMATIONS AT CHRYSOTILE, VERMONT.

1st. The quantity of merchantable asbestos available depends upon several factors:

a. The percentage of olivine in the original peridotite, as determined by the degree of differentiation in cooling as influenced by basicity and gravity.

b. The amount of fracturing that has taken place under the contraction of the cooling magma, producing joint planes, regional compression in mountain building, the throwing off of concentric shells from jointed blocks, expansion due to serpentinization and possibly to flow structure in the periphery of batholitic intrusions.

c. The presence of intrusives. These, wherever present, aid in the fracturing of the original peridotite, thereby producing both a cause and an effect of serpentinization. They also introduce magmatic waters that aid in serpentinization and possibly in crystallization.

2nd. The most favourable localities to exploit for asbestos are:

a. On the north or northeast sides of serpentine-bearing hills. Here the erosion has been deeper, and therefore productive zones are more likely to be encountered.

If the structure be a sill, the asbestos is more likely to appear at its base; if a batholith, at or near its centre.

b. In the immediate vicinity of faults or near the upper or lower contacts of the serpentine with intrusives.

3rd. *a.* Olivine magmas serpentinize and crystalize as chrysotile.

b. Olivine and pyroxene magmas give rise to serpentine and steatite, or chrysotile and talc.

c. Pyroxene magmas metamorphose into massive talc and steatite.

4th. A residual product, through chemical changes, is a silicious magnesite, as found at the Red Rocks, in Troy.

Uses.

According to J. S. Diller[1], of the United States Geological Survey, the fundamental property upon which the use of asbestos depends is its flexible, fibrous structure, coupled with which are the scarcely less important qualities of incombustibility and slow conduction of heat and electricity when the mass is fiberized and porous, which makes it valuable, not only for fire-proofing, but for insulating against heat and electricity.

Asbestos was first used for spinning and weaving to make incombustible thread, rope and cloth. Its value for these purposes was known by the ancient Greeks and Romans.

While asbestos is called the "coming material" and already enters largely into the economy of the world, it is, practically speaking, only at the beginning of its usefulness.

Hardly a month passes without some new use being discovered for asbestos; some application for which it is especially fitted and superior to anything else.

The principal application of asbestos is that pertaining to the manufacture of mill-board, paper covering, shingles and allied articles. About 65% of the mill fibre is absorbed in the manufacture of these products alone.

In the mechanical arts its value is indispensable. Some of the uses may be mentioned, as follows:—

Cloth.—Asbestos thread made from the highest quality of crude, is woven into many kinds of cloth and fabric from the lighter curtains of filmy lace to the heavy drop curtains of the theatres, amusement halls and the like and for the fire-proofing

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[1] J. S. Diller, Min. Resources U. S., 1907, pp. 766–781; 1908, pp. 697–706.

of the thousands of moving-picture shows now being introduced throughout all civilized countries. Asbestos cloth is also used for clothing of firemen and employees of smelting, glass, iron and acid works. Every automobile, whether gasoline or steam, uses asbestos packing. There is no other material so practical for the safety of life and property as asbestos.

Insulation.—Where perfect insulation is required, as in the handling of heavy electrical currents in the construction of modern buildings, no other material is so well adapted as asbestos when manufactured into insulators, switch-boxes and kindred articles. Asbestos is immune to most chemical agents that attack insulations. It makes the best covering for piping in connection with refrigerating plants, or for steam pipes, boilers and other places where a prevention of radiation or cooling is required, being used in this case as a binder for magnesia coverings.

Paints.—Under the name of "Asbestine," it is now used in the manufacture of certain paints, the fibrous structure having the property of holding up the heavier pigments in the paint. When used with paint containing lead and zinc, it adds certain properties which no other pigments can give.

Paper.—Over 30,000 tons of asbestos paper were used last year in building construction. This paper is damp-proof, as well as fire-proof, and its use is highly recommended by insurance companies.

Plaster.—Asbestic, or refuse, when mixed with caustic lime, produces a perfect fire-proof wall plaster for either inside or outside work, and its cheapness will make its use more general as the economic qualities become better known.

Fire-Proof Brick.—Composed of hydraulic lime, sand and asbestos. These bricks are now used where high temperatures are required, as lining furnaces, fire-boxes, etc. No other material will resist extreme heat so well.

Conveyor Belts.—Owing to their fire-proof and wearing qualities, and their recognized superiority to rubber, leather or canvas, asbestos conveyor belts are used where hot clinkers and other substances have to be disposed of. The durability of these belts also commends them in all cases where crushed rock, copper or other ores have to be handled in bulk.

Flooring.—Asbestos tiles and boards are used for floorings. They are impervious to heat or water, and their elasticity is as high as wood. They have the hardness of cement, greater durability than asphalt, are light in weight, will not crack, and are non-conductors of sound.

Household Goods.—Asbestos felting is made into many articles for the house, such as table covers, mats, rugs, gas-logs, fibre for grates, etc.

Asbestos Lumber.—This is an artificial wood made from asbestos fibre, which possesses all the qualities of the natural product, being susceptible of manipulation for building purposes with ordinary wood-working tools, and, in addition, has many qualities not possessed by the natural product. This asbestos wood is non-shrinkable, is fire-proof, does not deteriorate, and can be treated with ordinary oil paints, thus producing colour effects similar to those presented by the natural wood. Its value has been recognized by firms and individuals engaged in constructive work, and it has been adapted by some of the most prominent firms in the world; notably the builders of the large trans-Atlantic liner "Kaiser Wilhelm," whose interior is finished throughout with this very superior material. Factories have now been erected in Continental Europe for the manufacture of this product, and its use is being daily extended. With the extensive use of powerful currents of electricity in our modern homes, apartment houses, etc., many a catastrophe has had its inception from the simple contact of some heavily charged wire with a portion of the wooden rafters or lathing. This could have easily been obviated by using asbestos lumber and asbestos plaster-board.

The author could mention brake-linings, filters, protected metal, fire-proof linings for stoves and automobile tires; but, as every day develops some new use for this wonderful material, suffice it to say that asbestos has become an absolute necessity in our modern daily life; a universal article of commerce.

Discussion.

Mr. Cirkel:—A few words may not be amiss regarding the discovery of asbestos deposits in other countries, especially in the Island of Cyprus, in Siberia, and in Western Australia.

The asbestos deposits in Cyprus are in a highly decomposed condition near the surface. This is emphasized by the fact that so far the use of explosives has not been necessary. As a general rule these beds are worked on no definite plan; no depth is attained, and as soon as hard rock is encountered, work in that spot is discontinued and operations started elsewhere in soft ground. The asbestos is a "chrysotile," and resembles in some respects the Canadian variety. The size of the veins varies from ⅛th to 1½ inches, and the analyses of some specimens brought to my notice are encouraging. The peculiar reddish colour of the asbestos is attributable to the presence of a large percentage of iron. While the high-grade Thetford asbestos contains only from 2.5% to 2.8% iron oxide, the Cyprus variety contains 4.8% to 5%; the water content is the same, namely, between 1.3% and 1.4%; while the silica and magnesia remain within the permissible limit. The deposits are continuously worked throughout the year, and the number of persons employed in the industry range between eighty and five hundred, according to season. About three thousand tons of asbestos per year is produced, necessitating the handling of thirty thousand tons of asbestos rock.

In reference to the new Siberian deposits, I have received from a gentleman in Paris interested in those deposits, a number of samples, and also a private report by an engineer. According to this report, these deposits occur in the district of Tenissei, on the right bank of the Kamyshto River, a branch of the River Tenissei. Their distance, in a straight line from the latter, is fifty-two miles.

The asbestos formation takes in the foothills of Psajansk Mountains, in the vicinity of the Kamyshto River. The country formation is a crystalline limestone intersected by bedded masses of serpentine. From the description afforded me, it appears that these deposits occur in the Laurentian, and may be compared with those found in the Ottawa country, in the exploitation of which I was engaged for a number of years. All the Siberian deposits, it appears, are of limited extent; the veins occur within parallel serpentine layers, from six to eight feet wide, and from information received, have been exploited to some extent by shafts and drifts. The crude asbestos has a rough touch, is yellow in appearance, but the fibre when worked up is rather delicate, though also to some extent fluffy. The nearest shipping point is Krasnojarsk, and the total shipping costs to London are, it is estimated, from $35.00 to $40.00 per ton.

Asbestos deposits have been also discovered in the Pilbarra District, Western Australia. Mr. Soanes, a geologist of Perth, who has made a study of these deposits, speaks of them as being similar to the Canadian occurrences. Shafts to a depth of 140 feet have been sunk in a serpentine lode eight to ten feet wide, and the asbestos produced seemed to be a chrysotile, the crystallization in all the samples submitted to the writer for examination having developed vertically to the walls. The fibre *in situ* exhibited a brilliant wavy lustre, rarely found in the Canadian, except in the Laurentian or Templeton asbestos. However, some of the fibre does not possess the tensile strength required, and I believe that a quantity of the asbestos sent to Europe will not stand the tests for manufacturing purposes.

Another sample forwarded by Mr. Soanes, of Perth, represents vein-asbestos fragment embedded in a pale greenish serpentine, similar in appearance to raisins in a pudding. It is to be noted that all the fibres appear in their original crystallization; they are not distorted or twisted or broken in the sections of veins exhibited. This goes to show that the solidification of the serpentine took place after the formation of the fibre, because if this were not the case, the fibre would be crushed or torn to fragments.

Now, as to the origin of asbestos, some assert that the formation of asbestos pre-supposes the existence of fissures; others affirm that the asbestos fibre has been formed through the action of magmatic waters. From evidence which I shall presently produce, I am inclined to believe that fissures were formed previous to the crystallization of the asbestos fibre. We all know that certain gold quartz or other metalliferous lodes have been formed through the successive deposition of mineral matter within a fissure from the walls inwards. Take the case of a zinc-blende lode, of which I show you here a section. This zinc-blende lode, which is a typical deposition of metalliferous ores in a gangue, consists of the following layers, commencing from one wall of the fissure (Fig. I): blende, quartz, fluorspar, blende,

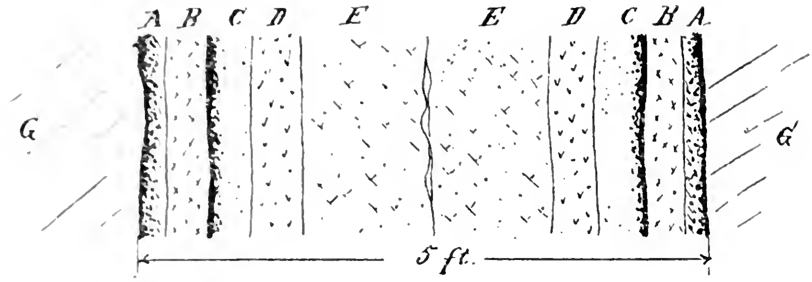

FIG. 1.

ZINC BLENDE LODE—Showing successive deposition of ore from the walls of fissure inwards, through lateral secretion of zinc blende and quartz. B.B. Fluorspar. C.C. Zinc blende. D.D. Fluorspar. E.E. Calcite.

barite, fluorspar, calcite. If you compare this half with the ore deposition of the other half of the lode, you will perceive at once that the arrangement of the single mineral streaks or layers is perfectly symmetrical. Now compare this section with the one illustrated in Fig. II. This illustration is a reproduction of

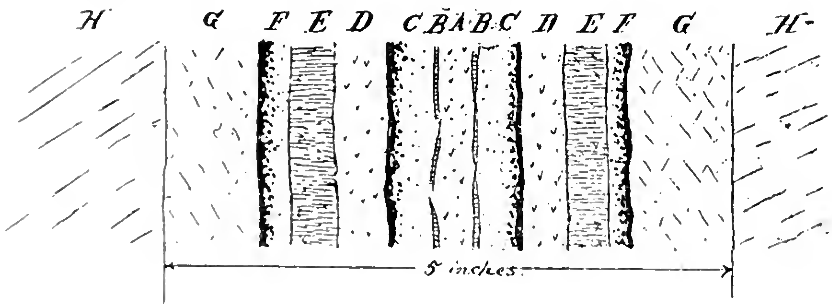

FIG. 2.

CHROME IRON VEIN.—H.H. Peridotite. G.G. Serpentine. F.F. Dark green serpentine with chrome iron. E.E. Yellowish asbestiform material with fibrous structure vertical to walls. D.D. Pale green or opaline serpentine with abundance of chromic iron. B.B. Asbestos vein, fibre vertical to walls. A.A. Serpentine and streaks of chrome iron.

a sample of asbestos serpentine which I found several years ago, It will be at once noticed in this sample an analogous deposition of mineral matter indicated by the streaky appearance; there are two sharp demarcation lines indicating the walls; proceeding from these inwards, we find the following perfect symmetrical arrangements:

HH peridotite.
GG Serpentine.
FF dark green serpentine with chromic iron.

EE yellowish asbestiform matter with fibrous structure vertical to walls.

DD pale green or opaline serpentine.

CC dark green serpentine with abundance of chromic iron.

BB asbestos veins, fibre vertical to walls.

AA serpentine and streaks of chromic iron.

It is not necessary for me to demonstrate the formation of these veins through successive deposition of the mineral matter from the walls of a fissure, which is so well indicated by these demarcations. This seems to clearly point to the fact that fissures must have been in existence throughout the serpentine mass before the solidification of the mineral matter therein; but it may be that these fissures may have been widened through the circulation of subterranean waters.

Another misconception which has been brought forward in recent treatises, is the crystallization of the asbestos fibre. It has been affirmed, and this with a great deal of emphasis, that the crystallization of asbestos fibre has taken place along a line, and that the formation of the fibre has started from this line outwards. I have here samples which disprove this theory. In a sample of asbestos from Black Lake the fibre is two inches wide, but we find nowhere a line or a break within the vein; there is absolutely nothing to indicate that the crystallization took place from a line between the two walls. Another sample shows in the middle a very irregular zigzag break in the fibres; now it is hardly conceivable that a crystallization took place from such a zigzag line outwards; it is far more reasonable to suppose that the fibres grew from wall to wall, and that these irregular break lines, similar to the teeth in a saw, formed the terminus of the crystallization from either wall.

Another sample in my possession comes from Western Australia. There is a break of the fibre in the middle part which is made up of serpentine. This break terminates abruptly; no trace of any kind is found on either side in the direction of this middle parting, bue we find a long silky fibre instead, vertical to both walls, no disarrangement can be found anywhere.

I would like also to direct attention to a peculiar occurrence of asbestos, which at one time was the subject of discussion at several meetings held by the Quebec Mining Association early in the 'nineties'—that is the Templeton (twenty miles north of Ottawa) occurrence. I was identified with the mining of this asbestos some twenty years ago; but before commencing actual operations, I made a study of the asbestos deposits of the Eastern Townships of Quebec, and found that there was absolutely no similarity between the two whatever. In the Thetford Black Lake district, I found a whole mass of serpentine extending over several miles, with an accumulation of asbestos veins through certain parts of it;—in the Templeton there was no such mass of serpentine: instead of this I found a mass of crystalline limestone, highly pyroxenic in character (Fig. III). The asbestos veins were confined to isolated patches and ellipsoid bodies with ringlike sections, having in the middle a core or kernel of a hard flinty pyroxenite. These bodies had a diameter of from 3 to 5 feet mostly, though one of them was mined which measured 60 feet in the longer axis.

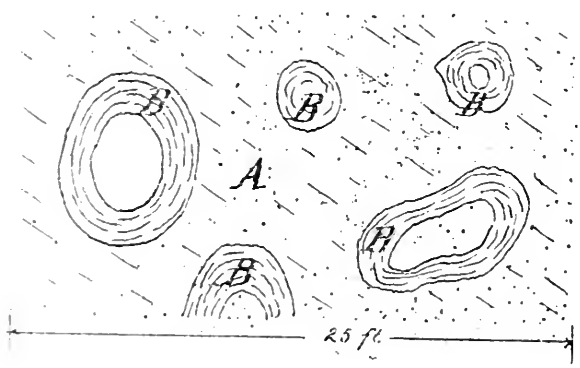

Fig. 3.

Section Through Templeton Laurentian Asbestos Deposits.—A. Crystalline limestone, pyroxenic. B. Serpentine with asbestos veins concentrically arranged.

The illustration (Fig. III) shows a section through the crystalline limestone formation. It will be noticed that all the sections of these deposits are in the form of rings, entirely separated and isolated from each other. The asbestos veins are indicated by the black lines in the diagram. They vary in width from 1/16 to 1 inch, are concentrically arranged, that is parallel with the walls of the serpentine, and hold an excellent product. I may, perhaps add that I extracted two carloads of crude asbestos which sold at the high price of $300.00 per ton,—an acknowledgment of the high quality of the material.

My object in calling attention to this mode of occurrence of asbestos-serpentine is to correct certain, "very grave misconceptions." I refer to the statement that magmatic waters are responsible for the production of asbestos fibre. We speak of magmatic waters only in connection with igneous rock, be they intrusive or volcanic(effusive). The crystalline limestone which contains these isolated bodies of serpentine, is a constituent member of the Laurentian formation, and is regarded strictly as a highly altered sedimentary rock. If the magmatic waters, according to Dr. Barlow and Dr. Richardson, are responsible for the production of the fibre, where then are these magmatic waters coming from in the case of the Laurentian asbestos deposits within the (sedimentary) crystalline limestone ?

The question of the origin of asbestos, as may be readily perceived, is a very intricate one; but in my belief the fissure theory, according to tangible evidence to be found in the various pits both in the Eastern Townships and in the Templeton districts, seems to me the only rational one; it may be possible, however, that in the Thetford Black Lake deposits the fissures may have been widened through the circulation of subterranean waters.

DR. BARLOW:—I have listened with a great deal of interest to Dr. Richardson's paper, and was glad to notice the emphasis he placed on the rôle played by magmatic waters in the production of asbestos, because I am of opinion that the prevailing excellence of the Quebec asbestos is largely owing to the presence and sufficiency of such heated waters, both accompanying and immediately following the intrusion and differentiation of the eruptives with which the mineral is associated.

At the last Annual Meeting I directed the attention of the members of this Institute to what seemed to me to be some very serious misconceptions that had arisen in the minds of many regarding the origin of asbestos, some of which had been occasioned by reading certain official, and what should have been authoritative, statements in regard to this subject.* Consonant with the views then expressed, I feel myself in disagreement in almost every particular with Mr. Cirkel's opinions, to which he has given expression in the address just delivered. Mr. Cirkel maintains that pre-existing fissures, presumably of megascopic dimensions

* Journal Canadian Mining Institute, Vol. XIII, 1910, pp. 438–443.

in the dunite or resulting serpentine, are essential to the formation of asbestos, at the same time illustrating his remarks in this connection by an exhibition of diagrams and specimens of veins (?) of asbestos. He gave especial emphasis to his conviction that asbestos veins are analogous in every respect to ordinary fissure veins. At the same time he infers that the material (Chrysotile asbestos) occupying these fissures has been brought from some distance, and that the veins have grown from the sides towards the centre. In these circumstances I would like to make it quite plain that in my opinion there is no necessity of a fissure as ordinarily defined and understood, the minute structural planes of the whole rock mass and its component minerals being all that is essential. These minute lines of fracture may be and usually are in the initial stages of the development of the asbestos of only microscopic dimensions, barely sufficient to act as planes of solution to carry the magmatic waters for the hydration and serpentinization of the dunite in their immediate vicinity. It is in this particular that the word "line" is used in its almost geometrical strictness. The evidence of the original presence of these planes of solution is usually disguised by the development of the asbestos fibres. The truth, however, of its existence is abundantly attested by the examination of the thin sections under the microscope. A photomicrograph of a thin section by N. B. Carmichael, M.A., of the School of Mining, Kingston, accompanying a paper by W. J. Woolsey, well illustrates this phenomenon.* A microscopic thin section illustrates exactly what is seen on a large scale in the working face of an asbestos quarry; while at the same time it enables one to study the manner of the formation of the asbestos to better advantage. The asbestos fibres (as very well shown in Mr. Carmichael's photomicrograph) begin to develop along a line extending outwards from this as a centre. The growth of the chrysotile is, therefore, outward, and not inward as stated by Mr. Cirkel. The asbestos has not been transported from a distance, and has, therefore, in this respect no relationship with the filling of ordinary fissure veins. While, however, denying the necessity of pre-existing fissures, it is obvious that there are certain larger fractures than those already mentioned, often of considerable dimensions, formed by the differential stresses set

* Canadian Mining Institute Journal, Vol. XIII, 1910, p. 415.

up in the rock mass during the processes of intrusion, differentiation and hydration. The presence of asbestos in such a situation is directly attributable to the alteration of the rock in the immediate vicinity. There was very little immigration of waters holding chrysotile in solution from any distant source. The so-called veins of asbestos are really made up of material developed *in situ*, and growing in direct proportion to the amount of magmatic waters supplied. They owe their presence in such purity and abundance in the Quebec occurrences because (a) of the great purity of the original rock mass, for, as shown in Mr. Dresser's lantern slides, the dunite often consists of 90% of olivine, and because (b) the magmatic waters have acted in such a way that a maximum of chrysotile has been formed with a corresponding minimum of the less valuable and massive serpentine.

In the Quebec occurrences as a rule a larger proportion of the rock is still unaltered and recognizable as dunite, except in the vicinity of the asbestos, so that there has been in this way a minimum of displacement and re-adjustment produced by the change in bulk of the resultant rock mass. This may account for the excellence of the Thetford and Black Lake chrysotile, while at the same time the complete alteration of the East Broughton outcrops would explain the destruction of what was originally good asbestos, and the product of a more than the normal amount of slip and mass fibre and picrolite, for the latter mineral is both under-developed and over-developed asbestos.

MR. DRESSER:—Speaking in a general way, the impression grows strongly upon one in following out the serpentine and allied rocks that the borders of the original joint planes have been the first parts of the peridotite to become serpentinized, since the largest and most persistent veins of asbestos generally occur along the joint planes. In such cases the action of magmatic waters has probably been the principal cause of the serpentinization. In other cases the asbestos veins are developed along fractures evidently due to regional compression, which took place after the rock had became solid and hence probably well cooled. In this case it is difficult to account for the presence of magmatic waters and the serpentinization seems much more likely due to meteoric waters, especially where no granite or later intrusions are known. So far I have not observed any fractures of importance in the peridotite which do not show some serpentinization of the side walls. Consequently while a large proportion of the asbestos may be due to the action of magmatic waters, I think that meteoric waters have caused a portion of the serpentine at least and probably also of the asbestos as well.

Dr. Barlow:—I am sorry that in previous remarks I seem to have created the impression that there were no fractures of megascopic dimensions along which the magmatic waters travelled, and thus assisted in the production of the asbestos. I wished to make plain, however, my opinion that such fissures are by no means absolutely necessary, and many of the present veins of asbestos may and doubtless have in many cases resulted from the widening and extending of originally microscopic veins. In addition, moreover, while I do not deny that meteoric waters have contributed in some degree to the formation of asbestos, such action has been extremely limited and is therefore unimportant from an economic point of view.

Serpentinization is, in my opinion, a deep-seated process, and one that can only take place below the influence of active weathering. It is quite distinct from weathering, as shown by the subjoined chemical analyses. With such an hypothesis, it is conceivable that serpentine can only exist at or near the present surface after the removal of a considerable amount of the overlying rock, as is evidenced by the Quebec occurrences. Serpentine, and especially asbestos, are much more stable and resistant products to ordinary atmospheric decay than the original dunite from which it has been derived. Weathering, or the action of meteoric waters, tends simply to the mechanical disintegration of the dunite, and the subsequent formation of a considerable amount of magnesium carbonates, of magnesium and nickel, silicates, hydrous iron oxides and chalcedonic silica. The carbonates of magnesium and probably very small quantities of carbonate of iron, as well as the silicates of magnesium and nickel, are sometimes deposited in veins or irregular masses; immediately below the heavier products of weathering, but they are usually almost completely removed by the infiltrating meteoric waters leaving a heavy soil or mantle of pisolitic iron ore (limonite and goethite) with occasional large fragments of so-called "chert" or chalcedonic quartz scattered about. The ore deposits resulting from the weathering of dunite and allied peridotite rocks consist of residual deposits of iron, nickel and magnesite. The nickel deposits of New Caledonia, Webster, North Carolina and Riddles Oregon, and the iron ores of Cuba are well known examples of residual deposits resulting from the action of meteoric waters on peridotite. The weathering of peridotite or dunite tends, therefore, to the formation of the simpler mineral substances already mentioned, rather than to the development of the more complex hydrous orthosilicate serpentine. The following analyses of dunite from Corundum Hill, North Carolina, show the chemical changes occurring in the first stages of its decomposition by weathering the result of long continued action of meteoric waters.

	I	II	III	IV
SiO_2	40·11	40·25	40·18	40·04
Al_2O_3	0·88	0·96	1·35	3·17
Cr_2O_3	0·18	.....	1·41	......
Fe_2O_3	1·20	2·71	10·97	12·15
FeO	6·09	5·97	....	.....
MgO	48·58	47·76	43·84	42·97
H_2O	2·74	1·54	2·01	2·14
Chromite	0·56	....	.....	...17
	100·34	99·19	99·76	100·64

I. Dunite, crystalline granular, apparently least altered; substrious greyish green to oil green in colour.

II. Altered dunite, granular, dull; colour, pale yellowish brown; from interior of altered nodule.

III. Altered dunite, granular, pulverulent; brownish yellow colour; from outside portions of altered nodule, harder part.

IV. Altered dunite, softer and more easily pulverized part separated from III by crushing without grinding and softening through a fine sieve.

The gradual decrease in magnesia, with a corresponding increase in iron and alumina, is very apparent. The water is practically the same throughout. In I it is evidently due almost wholly to serpentine and to limonite, or goethite, and kaolin in the last.

The analysis given under IV belongs to a rock made up approximately of the following composition: Olivine, 85%; Goethite, 7%; and Kaolin, 8%[1].

On the other hand, the following analyses will serve to show the change in chemical composition in the alteration of olivine and dunite to serpentine and chrysotile (asbestos). As dunite is a rock made up essentially and almost wholly of olivine (see analyses below), the alteration is precisely similar. Under I, is an analysis of olivine (chrysotile) from the Corundum Hill mine, Macon County, North Carolina.[2] II, dunite from same locality.[3] III, massive serpentine from the same locality.[4] IV, Chrysotile (asbestos), Broughton, Quebec.[5] V, Chrysotile (asbestos), Templeton, Quebec.[6] VI, Chrysotile (asbestos), Petite Nation, Quebec.[7] VII, Picrolite, Bolton, Quebec.[8]

	I	II	III	IV	V	VI	VII
SiO_2....	41·58	40·11	41·90	40·87	40·52	43·65	43·70
Al_2O_3....	0·14	0·88	0·71	0·90	2·10	.....	.....
Fe_2O_3....	.....	1·20	0·91	.....	.....	.....	.....
Cr_2O_3....	.....	0·18	.....	.....	.....	.....	.....
FeO.....	7·49	6·09	.....	2·81	1·97	1·46	3·51
NiO.....	0·34	.....	0·10	.....	.....	.....	.....
MgO.....	49·28	48·58	40·16	41·50	42·05	41·57	40·68
CaO.....	0·11	.....	.....	.....	.....	.....	.....
H_2O.....	1·72	2·74	16·16	13·55	13·47	13·48	12·45
Chromite	.....	0·56	.....	.....	.....	.....	.....
	100·66	100·34	99·94	99·63	100·10	100·16	100·34

As shown by the above analyses, the decomposition or alteration of dunite or olivine into serpentine involves a considerable loss of magnesia and a large proportion of the iron. This is made up by a corresponding increase in the amount of water. The water is all chemically combined in the form of hydroxyl and not as water of crystallization.

([1] and [2]) Pratt and Lewis, "Corundum and the Peridotites of Western North Carolina," 1905, p. 116. Also Chatard Bulletin U.S. Geological Survey, No. 42, 1887, pp. 55–56.

([3]) T. M. Chatard, Am. Phil. Soc., Vol. XIII, 1873, p. 362; also Bulletin U.S. Geol. Survey, No. 42, p. 55..

([4]) E. A. Schneider, Am. Journal Sc., 3rd series, Vol. XL, 1890, p. 308.

([5] and [6]) J. T. Donald, Trans. Gen. Mining Assoc., Quebec, 1891, p. 27.

([7]) T. S. Hunt, Annual Report Geol. Survey, Can., 1866, p. 205.

([8]) T. S. Hunt, "Geology of Canada," 1863, p. 472.

The chemical reaction which takes place in the development of serpentine from olivine (dunite) may be expressed by the following equation.[1]

$2(Mg\ Fe)_2{:}\ SiO_4{:}$	—	$(Fe\ Mg)0$	+	$2H_2{:}O$	=	$H_4{:}Mg_2{:}Si_2{:}O_9{:}$
olivine		iron and magnesia		water		serpentine

It is, perhaps, worthy of remark, in this connection, that the best examples of serpentine and chrysotile asbestos are in the Province of Quebec, where most of the products of weathering have been removed by profound glaciation. It is, on the other hand, significant that practically unaltered and fresh types of dunite may be secured in the near vicinity of the surface on the hillsides of North Carolina, which is unglaciated, and where weathering processes or the action of meteoric water has been operative for untold centuries.

MR. DRESSER:—I did not intentionally use the word fissure. A fracture would be quite sufficient to admit the waters whatever their source and so ultimately to give rise to an asbestos vein.

MR. F. L. NASON:—These discussions seem to me to be confined to commercial deposits and attempted explanations of the origin of chrysotile in dunite and olivenite. I wish to call attention to the fact that chrysotile is not confined exclusively to the above occurrences, but appears as an accessory constituent of many crystalline limestones.

I refer, for example, to the serpentine found in the white limestones at Montville, N.J. In these serpentines are found chrysotile veinlets, as in the serpentines of the Eastern Townships and Vermont. Both chrysotile and serpentine here are probably derived from amphibole.

At Tilly Foster iron mines, serpentine seems to be derived from chondrodite and some chrysotile is found at this mine. On the shore of Notre Dame bay, in Newfoundland, are a series of beds (?) of serpentine, seemingly of metamorphic origin. At least there is a stratigraphic sequence for 1,000 feet or more. The base is a coarser conglomerate consisting of rounded boulders of gneiss, quartzite, etc. This is succeeded by beds of coarse

(1) Pratt & Lewis, "Corundum and Peridotites of Western North Carolina," p. 119.

sandstone; these grade into fine sandstones; and are succeeded by beds of jasper alternating with fine-grained sandstones and finally pass into beds or strata of a talcose nature, then strata of serpentine 200 feet or more.

In these I noticed some fibrous mineral, which I assumed to be chrysotile.

The point of these references lies in this: The Quebec chrysotile seems to occur in eruptive rocks of which olivine is a prominent constituent. But the crystalline limestones of New Jersey and Tilly Foster, New York, and the serpentines of Newfoundland appear to be of unquestionable sedimentary origin.

MR. MORTIMER-LAMB:—In referring to the occurrences of asbestos in the Pilbarra district, in Western Australia, Mr. Cirkel stated he was given to understand on the authority of a geologist that these were comparable to our Canadian areas. This information, however, I conceive to be incorrect, since within the last few weeks I have received intelligence from a gentleman directly interested in the development of the field, to the effect that after expending a considerable sum of money in exploitation, it has now been decided to definitely abandon operations in view of the fact that the character of the product and the unfavourable conditions in respect of labour and market did not warrant further expenditure.

MR. CIRKEL:—I have here a sample of Japanese asbestos, This asbestos has a beautiful white appearance; the fibre is delicate, silky and fluffy; but it is also rather harsh to the touch, attributable, perhaps, to the presence of silica or calcite. In another sample from Japan, the asbestos resembles the Italian product, but it is at once perceived that the fibre is harsh, rough, and lacks the silkiness of the other sample. It more closely resembles the picrolite of the Eastern Townships.

I now take the opportunity to refer to a misconception common in foreign countries upon the discovery of an asbestos deposit. Thus it is thought that a serpentine lode from 6 to 8 feet wide, having several stringers af asbestos parallel to the walls, constitutes a valuable discovery of asbestos. Operations are commenced by shaft sinking and drifting, in ignorance of the fact that in the majority of cases this method of attack is too costly. Underground work has been successfully introduced at one mine in the Province of Quebec. At this property a stretch of ground, 400 x 800 feet square, has been explored and developed to valuable effect; but not every mine can safely indulge in the luxury of underground working. Asbestos rock is a low grade ore, and it is clear that such small lodes, as are from time to time discovered in foreign countries, cannot be profitably mined by this means. Even in the Canadian asbestos field, mining and milling per ton of rock costs between $1.10 to $1.20, excluding administration expenses; the returns being about $1.90 or $2.00 per ton, leaving but a small margin of profit.

Mr. J. J. Penhale:—I am glad that Mr. Cirkel has at last brought this discussion within range of my understanding. Now that it has narrowed down to a basis of dollars and cents, I can follow it with some degree of intelligence. I am one of a few here present, whose work begins where that of the geologist apparently leaves off. I am not vitally interested in how asbestos occurred or was deposited in the rock but I am interested in how to get it out of the rock and into the bags.

The proceedings this morning have dealt entirely with asbestos deposits outside of the Province of Quebec and it may now be permissible to discuss here their commercial aspect and the possible effect their development is likely to have on the asbestos business generally and on the Quebec mines in particular.

Reference has been made to the deposits of Sall Mountain, Georgia. These have been known and exploited for a number of years; but as it is a different variety to the Canadian and not at all suitable for the uses to which the Canadian is put, it may be dismissed without further consideration.

In the Grand Canyon, Arizona, there is a deposit—and very excellent fibre it is, too, the best I have ever seen outside of Quebec. This is confined to one or two veins, lying nearly horizontal in the serpentine overlying the granite. There is only about four thousand feet of limestone and sandstone on top of it. A carload of nice crude was mined there but when I tell you that we packed this out on burros and it took them seven hours to climb out of the Canyon with two 60 pound bags, that we then had to haul it eighteen miles to the railroad, you will understand that I have no need to say anything more about that particular deposit.

Coming to the deposits in the northern part of Vermont, while they may be interesting to the geologist, they have, so far, shown little if any value as a source of supply, although they have been given more or less attention for the last ten or twelve years.

The most important deposit so far discovered in the United States is that in Wyoming. These have a potential value, but at present they can scarcely be considered as a factor in the business. I spent a little time in the Caspar district, something over a year ago, and I saw some interesting outcrops of asbestos there. I will say in all frankness, that if some of the rock I saw there was on a corner of our property, I should not allow it to remain there undisturbed. There were several places where some work had been done, all of them from eight to twenty five miles from the railroad. The cost of haulage from these points to the railroad was given as $12.00 per ton. I am very sure that this was not overestimated, but even at that figure and the added freight rate to the Eastern Cities and the seaports, would be enough to make it impossible to deliver their product, their low grades especially, in the markets in competition with the mines of Quebec. The latter can deliver their product from the mines to English and Continental ports for $5.00 to $8.00 per ton.

Prof. Dresser has read us a description of the Russian mines and has given the figures of last year's production, as prepared by Mr. Anrep.

The product of these mines is practically the only serious competition we have to-day. Russian fibre has been known in the market for the past twenty years. This fibre is not so well adapted for manufacturing as the Canadian.

Last September I had an opportunity of seeing how it was used in a factory on the Continent. First they spread a layer of Canadian fibre, then a layer of Russian and so on until they have a mixture of about two-thirds Canadian and one-third Russian. In this way they work it up, using it as a "dope" for our good Canadian stock.

With this, again the cost of transportation is a serious factor. The production of the Russian mines for last year is given as 10,000 tons and the number of men employed is given as 15,000. Even though labour may be cheap there, if it requires one man and a half, per ton of production, per annum, as these figures indicate, it would appear that there is not much to be feared from that quarter.

I do not think we have anything to fear in the way of serious competition from any of these districts for a long time to come. None of them can challenge the position we hold of being able to supply the bulk of the world's consumption of this particular mineral; and this is due to the many natural advantages such as convenient transportation facilities under which we operate. The chief advantage of all is that of being able to produce asbestos of a quality that, so far, is unequalled in all the world.

If the uses to which asbestos is put and the consumption continues to increase, as it has done in the past few years, while we shall still hold the superior position, due to the many advantages we have, there will still be room for the product of new districts.

Mr. Cirkel raised the point of the impossibility of doing underground mining at a profit. The deposits of the Grand Canyon can only be mined in that way, because of the overlying rock. Sixteen years ago I did some underground work in going after a very fine vein of asbestos, and I produced fibre from these underground workings at a very low cost, a cost that would compare very favourably with the cost of production to-day. The principal trouble I found to be the restricted area over which we could work. Mr. W. H. Smith of Thetford has carried out the most extensive scheme of underground workings that has yet been attempted in asbestos mining and from what I have seen personally, I have no reason to doubt Mr. Smith's veracity when he says it is carried on at a profit.

Mr. W. H. Smith:—There is nothing in the world which would have caused me to talk to the scientific gentlemen assembled here, except to contradict a statement. It has been said that it was impossible to adopt regular underground methods of mining asbestos. I speak, however, from the standpoint of a man who has certain demonstrated facts behind him. I have to-day in the Bell asbestos mines four-and-a-half miles of underground work. We display a sign above our office in which the statement appears that we have the most productive mine in the world and that statement has not been challenged. Our material mined from underground workings is passed through the mill without requiring to be dried. That is a great advantage in severe weather. From a point of view of dollars and cents, I will admit that it costs more per ton to excavate the rocks in headings and stopes than it does in the open pits, but we reap the benefit to a greater extent in the milling. We do not follow the veins, as a matter of fact the ore does not exist in regular veins; the rock is full of it; there is nothing but asbestos in sight.

MR. CIRKEL:—When I referred to underground mining I did not wish to convey the impression that this method is not economical in the Eastern Townships; I am far from venturing on such a statement. What I desired to emphasize was that the discoverers of a small serpentine lode with a few stringers of asbestos, not familiar with the vagaries of asbestos mining, have a very wrong idea as to the profits of such an undertaking. I would not for one moment criticise methods of asbestos mining in this country. If other mines in the district do not emulate the example set them by the company to which reference has just been made, that is their own business.

MR. FERRIER.—I have been away from my native land so long that I am just beginning to realize how many things I have forgotten. My memory has been refreshed, however, in one particular by Mr. Nason's remarks with regard to the Montville, N. J., chrysotile. He and I were colleagues at one time on the Geological Survey of New Jersey, and I am familiar with the Montville locality and also with that at Templeton, Que. I do not think the former represents a unique occurrence, in fact, there are many points of resemblance between the two occurrences. At one time, in New Jersey, I got samples from both places mixed up and could not tell them apart, so I gave them away to friends!

If my memory serves me rightly, I think that some of Dr. Adams' work bears on the point that Mr. Nason made regarding the formation of chrysotile veins in dunite and peridotite. I cannot agree with Mr. Nason altogether, because I think that they can also be produced from the pyroxenes. Our president has done a lot of work along these lines and, personally, I would like to hear a few words from him on the subject.

DR. ADAMS:—The asbestos in the Laurentian District of Canada occurs, as Mr. Cirkel has said, in quite a different manner from the asbestos deposits of the Eastern Townships. It is found in connection with masses of serpentine embedded in the limestone of the Grenville series, and in this respect resembles the New Jersey deposits. Many years ago Professor Merrill found that the larger nodules of serpentine, which occur in the white crystaline limestones of New Jersey, when broken across transversely displayed cores of white pyroxene.

When working about Rawdon, on the geological survey of the Laurentian District, to the north of the Island of Montreal, which I carried out some years ago for the Geological Survey of Canada, I found that the Grenville limestone in that district was in many places filled with rounded grains or lumps of serpentine, and that when the larger of these lumps were broken across they displayed cores of white pyroxene like those found by Professor Merrill in New Jersey. This pyroxene may possibly have resulted from the alteration of impurities in the original limestones during the process of intense metamorphism which the limestones subsequently underwent, but it is more likely that the growth of the pyroxene was induced in the limestones through the influence of the adjacent intrusions of granite.

The asbestos in this Laurentian region is merely a fibrous form of this serpentine thus produced by the alteration of these pyroxene masses in the limestone.

The origin and mode of occurrence are thus quite different from that of the great deposits at Thetford and elsewhere in the Eastern Townships, where there is an entire absence of limestone, and the asbestos occurs in serpentine derived from the alteration of great intrusions of peridotite.

PROF. J. F. KEMP:—There is an old idea that was widely current in its day, that serpentine is the product of surface weathering. We have been tending, in late years, however, to the belief that the formation of serpentine is a deep-seated process. Surface weathering yields carbonates, jaspers, iron ores, such as limonite and certain disintegrated residuals. The carbonates run away in solution and the iron ores may remain behind in a greatly concentrated condition, as we find them to-day in north-eastern Cuba. Since the serpentine itself yields to these changes and has already been formed from olivine and magnesian pyroxenes, we cannot avoid the conclusion that different conditions are demanded for its production, *i.e.*, deep-seated ones.

On the other hand, in the dunites of North Carolina we see an almost pure olivine rock, much crushed and granulated, outcropping at the surface, and yet composed of perfectly fresh olivines. If surface weathering produces serpentine, one would think that in the dunite areas, everything were favourable to its production, and yet it fails. Some support is therefore afforded to the view that the chrysotile is due either to magmatic waters or to atmospheric ones, which had percolated downward to regions of heat and pressure.

I am reminded of a third form of asbestos, not of any commercial value, but perhaps worth mention. The northern end of Manhattan Island, in New York City, consists of dolomitic marble, now regarded as Pre-Cambrian. When quarried for a ship canal some years ago the marble revealed a few vugs or cavities lined with quartz crystals, over which was spread a delicate web of asbestos, like lace-work. The asbestos had surely crystallized from solution and had come to rest supported by the points of the crystals.

MR. MCEVOY:—I do not look at this question through a microscope, but rather take a common-sense view of it. While it is possible that some of the smaller veinlets may have been formed in the manner at present favoured by the majority; in the case of the larger veins there are two arguments strongly against that theory. One is the even and clearly defined walls of the veins, and the other is the purity of the fibre contents.

If the veins were formed by crystallization, in place growing from a centre plane of fracture to each side, it would be only natural to expect to find veins which were irregular with uneven walls, in fact, veins which did not show the characteristics of true fissure veins. It would also naturally follow that the impurities of the country rock would be found more frequently in the fibre.

Perhaps the fact that these veins are in a rock of such similar composition to the veins themselves has had an undue influence on the minds of those studying the question. In this respect, would it be sound reasoning to conclude that because a quartz vein is found in a massive bed of quartzite, it must therefore be the result of the best attempt of the quartzite to crystallize under the action of magmatic waters?

The fact that the serpentine rock on each side of the vein is altered to more or less pure serpentine is quite as much in keeping with the true fissure vein theory as with the other, as it is usual to find the wall rock in the former case altered to some extent and even impregnated with vein matter.

THE BREAKING OF ASBESTOS-BEARING ROCK.

By Edward Torrey, Blake Lake, Que.

(Annual Meeting, Quebec, 1911.)

In asbestos milling, the rock breaking may be considered as having two objects: first, the parting or separating of the asbestos veins from the containing rock; and second, that which must be included with this operation while air separation is used, the "opening" of the fibre to such an extent that it may be picked up by a current of air of moderate velocity. The air velocity must be kept moderate so that it will refuse all but the smaller pieces of rock, so small that they may be classed as sand or dust.

Breaking or crushing to an unnecessary fineness is to be avoided, as it not only means a decided waste of power, but also introduces a very troublesome element, sand or dust, into the remainder of the process. The "opening" must not be carried too far, for this will destroy the "life" of the fibre, and the product will become "clammy." Nor must the delicate crystals be broken so as to shorten their length. Either of these occurrences will seriously lower the value of the product. Moreover, it is more difficult to clean the sand or dust from fibre that has become "clammy." It may be noted here that either of these considerations militates against the use of any breaking machine in which attrition appears as the whole or any part of its action. For it seems evident to a degree requiring no proof or illustration that attrition, meaning the destructive rubbing together of the particles of rock under treatment, must injure any fibre which is mixed with it.

The rock-breaking machines now in use in asbestos milling may be broadly divided into two classes: those which break by crushing the rock between two unyielding and advancing surfaces and those which break by impact of the rock at very high velocity against an unyielding surface. In the crushing class may be included jaw crushers, gyratories and rolls; while the impact class is represented by machines of the cyclone type.

As rock comes to the mill, measuring over two feet, the crushing, of course, proceeds in stages; and a discussion of the relative workings of the two classes of breaking machines mentioned is concerned only with the sizes adaptable to impact breaking, which practice seems to limit to a maximum diameter of from 1½" to 3".

The old cyclone, which has been used for so many years in asbestos milling, consists of two propeller-shaped beaters of the same hand, mounted overhung, on separate shafts on the same centre line. The beaters facing one another with small clearance between, are driven in such opposite directions that they throw toward their common centre, and are surrounded by a bowl built close to them, except at the top, where it extends some distance upward in box form with covered top. The feed is through a hole in the bowl behind the beaters, and the exit is through a hole in the side of the box-shaped part at the top. The action is very indeterminate; but we are sure that most of the rock breaking is done by a sharp blow or impact between the rock and a resisting surface. Whether the velocity of impact is possessed by either or both matters not at all, since motion is relative. As a matter of fact, all three phases occur in this machine; but that its action is not by impact alone, and therefore that it is not a true impact machine is evident when its construction is nalysed. The rock must crowd between the beaters, and between the beaters and bowl, and thus suffer attrition to the detriment of the fibre and the machine, even with a strong air current to aid the exit of the fibre.

Besides the injurious action on the fibre, the machine has mechanical defects which have always been a source of annoyance and heavy expense, as represented by frequent breakdowns, continual replacement of wearing parts, short life of belts and extravagant use of oil. A frequent cause of breakage is the lodgment of a piece of steel or very hard rock between the beaters. Notwithstanding its objectionable features, the machine has remained in use, and there can be no doubt that this preference may be attributable to its one good feature, namely, the main principle of its action—breaking by impact. At first thought it might seem that if the rock be broken, it matters little whether this is accomplished by impact or otherwise. There is, however, a considerable difference in result.

If it were possible to follow with any degree of refinement the breaking down of the structure of individual pieces of rock in their passage through the two types of machines, it would be easy to observe the difference in the two ways of breaking. This is hardly possible in crushing machines and decidedly impossible in impact machines. The action may, however, be followed analytically in an illustrative way; illustrative, because it would be fruitless to attempt any refinement in the mechanics of the problem, like the use of the calculus for example, when the factors entering into it are considered. Tension, compression, shearing, elasticity, plasticity and, in impact breaking, the limited time allotted to the action leading to the consideration of waves of compression, together make a rather formidable array.

In order to avoid following an almost infinite variety of shapes it is advisable to assume an average. A properly made composite photograph of a large number of rock pieces of the same weight would show a sphere with a solid centre merging into a hazy exterior, which will probably answer as well as any for an average sample, the haziness to be represented by a very rough hewn surface. If now the jaws of a vice are gradually brought together on the sample, the first effect will be to break the rough points and edges in contact with the jaws, into dust, which will "flow" into the hollows, forming areas of resistance against the advancement of the jaws, between which areas will be included a column of resistance. The remainder of the sphere forms an envelope or container for the column, and herein differs from the usual cubical test piece. When the resistance to the further formation of resisting areas becomes greater than the resistance to compression, there results a breaking down of the structure in the column of resistance, and a splitting of the envelope, probably by the action of wedge-shaped pieces being forced through the body of the sample, on the surfaces of which is a very fine breaking down of the structure. Certainly comminution is very noticeable throughout the column of resistance. Dr. Kalb found by experimenting with glass spheres passed through a set of rolls, a reduction to fines of over 5%. Asbestos-bearing rock, with its different physical structure, will form larger areas of resistance, and will probably show a greater reduction to fines. After the breaking down of the column, some of the pieces of the now broken envelope may fall from between the jaws; but the tendency is for them to hang, and the action in the original piece to repeat itself in them, the number of repetitions depending on the degree the jaws are closed. It sould be noted that as the jaws are more and more closed, they are no longer acting on an isolated piece, but on a crowded group, among which there is found to be an amount of attrition which increases with the further closing of the jaws. While the first closing of the jaws exemplifies the action of the crusher class under free feed, their further closing parallels the action of choke fed machines with incident attrition, and also shows how a free feed may develop into a choke feed by too great a reduction at any one stage.

In breaking by impact, the application is entirely different. It now exists in the rock itself, by virtue of its mass and velocity, and moreover in every particle of it; so that when the spherical sample is hurled against a resisting surface, the first action is to build up a resisting area, as in the case of jaw crushing, with its incident dust, but only one surface instead of two. Assuming a plane through the point of contact of the sphere and the resisting surface, and normal to the latter, dividing the sphere in halves, the resultant of the forces by which each particle of each half is advancing toward the resisting surface will pass through the centre of gravity of each half. These resultants, together with the parallel resisting forces passing through the point of contact, form a couple in each half, tending to open the sphere on the assumed plane, hingeing about the point of contact. It might seem that the tendency would be to open like an orange; but it is more probable that the break would follow the path of least resistance, which would be on the assumed plane. For, as shown by Rittinger, the amount of work done in actual crushing is measured by the increase in superficial area, and splitting on the centre plane would add the least area and therefore offer the least resistance to breaking. The half spheres are not suggested as an end product, but as the first effect of breaking. There probably follows a certain amount of slivering, the building up of more resisting areas, and a similar breaking up of the smaller pieces until the stored work is exhausted. That the tendency is to break as suggested, seems to be borne out by the fact that billiard balls break in this way, and especially by the appearance of a 1″ nut of coarse grained iron which was broken in two by impact, as nearly like half-spheres as its original form would permit. The grain at the break indicated very clearly that the halves had been pulled apart and not sheared. It appears from this that impact breaking is clean cut, and is less given to the production of fine sand or dust, which we have seen is troublesome and is, moreover, a great waste of power. For, to emphasize a well known fact, it is apparent that, weight for weight, its production means a relatively great increase of superficial area over the production of sizes slightly above it, and therefore represents a relatively greater use of power.

It should be noted that, while a crushing machine may be set with a definite discharge opening, limiting the product at least in one dimension to a definite maximum size, the impact breaker imparts to each piece of rock a definite amount of stored work in porportion to its weight, and when this has been used in breaking or otherwise wasted, there is a stop to all further breaking. Therefore the impact breaker cannot be set to give a product of limited size, but acts merely as a reducer of the size or, rather, sizes of the feed.

One condition, and a very important one, peculiar to impact breaking, is the extreme suddenness of the applied force and the almost infinitesimal amount of time allotted to the completion of any one stage of breaking. An effect of this may be well illustrated by two balls of viscous tar, one hurled against a resisting surface, and the other pressed slowly in the jaws of a vice. While the former will be shattered, the latter will not be broken, but will be flattened, absorbing a considerable amount of energy. It has undergone plastic deformation. Now all rock is plastic to some extent, and while its slight plasticity compared to that of viscous coal tar does not really appeal to the senses, yet, when we consider that the velocity of impact in ordinary practice runs as high as 15,000 feet per minute, it is not difficult to conceive that there is a considerable difference in breaking by impact and crushing, due to viscosity of the rock. It is known that the rock, broken in the crusher type of machine, undergoes plastic deformation, and this is an admitted waste of power of no small proportion in this form of machine, which cannot be charged against the impact type, at least not to the same extent. Therefore again in this particular the impact wastes less power than the crusher type of machine.

Another point in connection with impact breaking may be well brought out by example. Remembering that the work stored in a moving body varies directly as the mass or weight when the velocity remains constant, if a 2″ sphere be impacted with just sufficient velocity to break it in halves, its superficial area will be increased by the area of a 2″ circle. If now eight 1″ spheres are impacted at the same velocity, to break them in halves would require an increase in their total superficial area equal to the area of eight 1″ circles, which increase is twice the area of the previous 2″ circle. But together they store only the same amount of energy as the 2″ sphere, since their total weight is the same, which is therefore insufficient to break them. The energy put into them is lost; but it is only half the energy that would have been required to break them. It, therefore, appears that theoretically each speed of impact has a limiting size, below which it cannot break, and that in this particular, impact machines again show less tendency toward comminution and, further, a saving in power. Small particles have a greater resistance to motion in air than large ones in proportion to their weight, and this tends to further lower their speed of impact, as they are sure to meet adverse currents or eddies, even though the air may follow them in general direction. It should be noted that in the case of impact of "opened" fibre, both of these considerations indicate that it would be very slightly injured, if at all, by any speed of impact which is used for the breaking of rock.

So far the particular action of breaking on the fibre itself has not been given any particular attention. The problem may, perhaps, be best considered in a general way.

At the stage of rock breaking with which we are interested we find a mixture of the following: plain rock of various sizes; rock with contained fibre; unopened fibre, generally in solid pencil form, too heavy to be picked up by the air current; and "unopened" fibre. The last may be withdrawn by air suction; but it must still be considered, as the first part of any further treatment of the mixture may cause its reappearance.

To treat this mixture by machines of the crushing class, remembering the objects to be attained, as outlined, the first necessity for further crushing is a release of the contained fibre. Assuming that this has been completed, there still remains the fibre in pencil form to be opened. To get at this it is necessary to crush further and to a fineness that will reach the fibre in pencil form, and much of the longest mill fibre may appear in this form even less than $\frac{1}{4}''$ in diameter and still too heavy for the air suction. All of this must be accomplished with the least possible amonnt of comminution and, more particularly, without injury to the fibre, which, judging from the action of the crushing class of machines, is rather difficult of accomplishment, even in feeding free. For the wear of the crushing surfaces makes slight reduction per stage difficult to maintain with the smaller sizes of feed, and a heavy reduction is injurious as tending toward attrition, as has been shown. Even with slight reduction per stage, it is difficult to keep the feed from bunching, which constitutes the occurrence of choke feed in patches over the crushing surfaces.

On the other hand, let us follow this mixture through a true impact machine that impacts each piece of rock separately at each stage. The contained fibre, it would seem, should be more effectively opened by repeated impact than by repeated crushing between jaws, when the effects peculiar to impact breaking are taken into consideration, as previously outlined. If this be true, and practice seems to verify it, it is important in that it is a release from the necessity of carrying the breaking as far as jaw crushing would require, for the purpose in hand.

The fibre in pencil form requires a speed of machine sufficiently high to insure that it be opened. Although it occurs in small sizes, on which it has been seen the action of impact is comparatively slight, it must be remembered that when not reinforced by including rock, the tensile strength across the fibres is very low, so that an excessive speed of impact is not necessary for proper opening.

"Opened" fibre, as has been noted, can scarcely suffer injury.

If it is admitted that the preceding suggestions on the effects of impact breaking are essentially correct, then it seems safe to conclude that breaking machines, acting purely by impact, should be particularly well adapted to the milling of asbestos rock, and this leads to the consideration of a machine which shall be as nearly as possible a true impact breaker, and the following is suggested as essential to the design of such a machine.

In order to avoid impacting a piece of rock on one just preceding it, it is necessary to use a very large impacting surface and to make the rock feed, or rather stream, intermittent. The large impact surface being unwieldy should be made stationary. This necessitates imparting the velocity of impact entirely to the rock. The danger of breakage may be avoided by allowing ample space between the moving parts and the impact surface. There will be considerable wear and serious loss of power by friction of the rock on the moving parts in bringing it up to velocity, which latter may be more than offset by the economy in power due to breaking purely by impact. The wear on moving parts and on the impacting surface should be handled by proper facing or wearing pieces. The amount of metal discarded by renewals to be kept low by shaping the wearing pieces as nearly as possible like the volume lost by wear, or *e.g.* by making these parts as light as practicable to give the necessary amount of wear. Multiple impacts to be secured in the same machine by successive mountings on the same shaft. Belts to be made of ample width and proper speed and to run over pulleys of fair size. Pressure on unit area of bearing surfaces to be low in order to avoid excessive use of oil. Accessibility to be as far as possible secured, and, what is probably the dominating requirement in a machine of this kind, it must be made as nearly as possible "fool proof."

Sometime since the writer attempted the design of a machine on these lines, and regrets the absence of exhaustive data for comparison with the preceding suggestions, although twelve machines have been installed, of which six have been in operation for eighteen months. While only general conclusions can be given, as drawn from observation, these may prove of interest. It may be said, meanwhile, that the results obtained have fulfilled expectations.

The danger from breakage by pieces of steel passing through the machine is practically nil. For example, a 2½″ nut weighing 3¼ lbs. accidentally passed through two machines in succession while these were in operation, without causing the slightest damage to either machine.

The wear amounts to about 20 lbs. of manganese steel per 1,000 tons of rock, and the discard to abou 65 lbs. per 1,000 tons. The wearing pieces are large enough to last for two weeks and over, during which time the machine requires no other attention than the usual oiling.

Three of the machines now in operation, when under a feed of ten tons per hour, show a consumption at the motor of 20 h.p. as nearly as can be estimated. This is about 17 h.p. at the machine, or 1.7 h.p. per ton per hour. These figures refer to machines whose feed will pass a 2″ ring, breaking in two stages per machine. The rock passes once through and shows a dump very clean from "unopened" fibre.

The only reliable power data at hand on the old type of cyclone are from a test made two years ago on machines fed at ten tons per hour or less, and showing a consumption of over 80 h.p., per machine, or 8.0 h.p. per ton per hour. As this is a very heavy feed for this machine, the figures may not constitute a fair comparison.

The production of dust is very noticeably less, judging from the appearance of the fan discharge.

A group of these machines in concurrent operation with a group of the old form of cyclone on the same kind of rock have shown a decided difference in the fibre product. A very conservative estimate showed an increase in the value of the product of 33% due to a greater percentage of the better grades in the product, indicating a lesser breaking of the fibre crystals. The amount of fibre per ton of rock was increased by 3%, probably due to a better opening of the fibre; but this cannot be stated positively unless it is confirmed by the appearance of the tailings. The fibre also showed far more "life" and the mill tailings less unopened fibre, as well as a more uniform breakage; that is, less fines and fewer large pieces. Remembering the results to be obtained, however, even breakage, or fine breakage, is an item of no value as a test of efficiency in a breaking machine; for the true test of efficiency is the absence of "unopened" fibre with the minimum breakage.

One interesting and very noticeable feature is the difference in the appearance of the rock pieces in the tailings. Those from the new machine have very sharp edges, while those from the old Cyclone show dull edges. The latter are probably indicative of attrition.

DISCUSSION.

MR. DENIS:—I have seen Mr. Torrey's machine in operation and I would like to hear from the users of the old type of cyclones what the advantages of the old cyclones are over Mr. Torrey's. His machine struck me as being very much superior to the older type.

MR. W. J. WOOLSEY:—I have already held several discussions with Mr. Torrey concerning the principle of operation of his machine, and concerning its applicability to the crushing of asbestos rock, and I cannot doubt that the principle, namely, breaking by impact, is the correct one in practice. Breaking by this method, although with some slight modification or variation, has been tested by Mr. Pharo, who has had a very extensive experience in the milling of asbestos. He has arrived at the conclusion that the attrition cyclone injures the fibre, is wasteful of power, and costly in the matter of repairs. My own conviction, agreeing with this, is that in the crushing of asbestos rock, less duty should devolve on the cyclone, the process being carried as far forward as possible by the employment of standard jaw crushers and rolls. As a final process, however, for the recovery of short fibre in the rock, the cyclone has demonstrated its worth, and will not be discarded until operators have satisfied themselves that a device designed to replace it offers very superior advantages. Meanwhile, Mr. Torrey's breaker represents a new and sound idea.

MR. TORREY:—There are a few points I should like to emphasize. The appearance of "opened" fibre in the mill tailings is not due to defects in the breaking machine. It must be charged to the separating device. Nor is fineness of breaking an indication of efficiency, but decidedly the opposite. For reasons noted, the coarser the mill tailings, the better—provided there is a minimum of unopened fibre showing. But coarse tailings indicate a machine which can open the "pencil" fibre without the necessity of fine crushing.

ON THE SLATE INDUSTRY IN SOUTHERN QUEBEC.*

By John A. Dresser, Ottawa.

(Annual Meeting, Quebec, 1911).

The slate deposits of commercial importance in southern Quebec as far as known are all of sedimentary origin. The black slates are of Ordovician, and the coloured of Cambrian age. In a number of places quarries were opened between thirty and fifty years ago; but most of them were soon closed from one cause or another, principally, it would appear, from an insufficient market at the time they were worked. At present the market conditions have apparently changed greatly for the better and the slate deposits might properly receive renewed attention.

General Geology.

Three anticlinal ridges of crystalline rocks, probably of Pre-Cambrian age and mainly of volcanic origin, extend in a north-easterly direction through southern Quebec, and form the Sutton mountain, Stoke mountain and Lake Megantic hills. The basins between these ranges of hills, are each about 25 miles in width and are in general underlain by rocks of Cambrian age around their borders, while Ordovician strata occupy the central and greater part of the bearings. On the east side of the Sutton range a belt of serpentine and related intrusive rocks occur along or near the contact of the Cambrian and Ordovician sediments. In the Ordovician, near the contact with the serpentine, several of the most important slate deposits of the district are found. There are other deposits in the Ordovician and in the Cambrian that are not

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situated near intrusive rocks; but hitherto all the production of commercial importance has been from those deposits near the serpentine.

Black Slates—Ordovician.—The "black" slates are all of Ordovician age, being the argillaceous part of the lower Trenton (Farnham) formation. They are of dark or bluish grey colour and generally have an excellent cleavage which dips nearly vertically and may be at any angle to the bedding planes. In general character and geological position they correspond to the slates of Montpelier and Northfield in Vermont. They have hitherto been the principal source of production in Canada, and are the only slates quarried in Quebec for several years past.

Details of some Deposits.—Four of the best known deposits of slates of this type occur near the contact with serpentine in the county of Richmond. These are the New Rockland quarry in Melbourne, range IV, lot 23, the Melbourne or Walton quarry, Melbourne, range VI, lot 22, the Steele or Bedard quarry in Cleveland, range XV, lot 6, and the Danville quarry in Shipton, range IV, lot 7. The distance between New Rockland and Danville (the extreme points) is about fifteen miles, but the slate-bearing formation continues for a much greater distance.

These quarries were most actively operated in 1889, in which year they were described by Dr. R. W. Ells,* as follows:—"The largest slate quarry at present in operation in Quebec is that of the New Rockland company. This was first opened in 1868 and has been worked almost continuously ever since. It is situated on a rise with an elevation of about 500 feet above the St. Francis river, which is four miles distant to the north, and has at present a working bench 200 feet deep. The slate cleaves readily, is very free from pyrites, impervious to water and equal in every respect to the celebrated Welsh slates..........To the northeast of this is situated the old Melbourne or Walton quarry, on lot 22, range VI, Melbourne, about two miles distant from the St. Francis river. This quarry was opened by the late Mr. Walton in 1860 and was worked for about eighteen years when it was closed. A very large quantity of slate was extracted of a quality similar to that of the New Rockland quarry and the workings were of very considerable

*An. Rept. Geol. Survey of Canada, 1889. Part K, pp, 129, et seq.

Fig. 1

New Rockland Slate Quarry, Looking Northeast

... 200 feet in length, 75 feet wide, and nearly 200 feet deep. The cleavage of the slate dips at a high angle to the Southeast

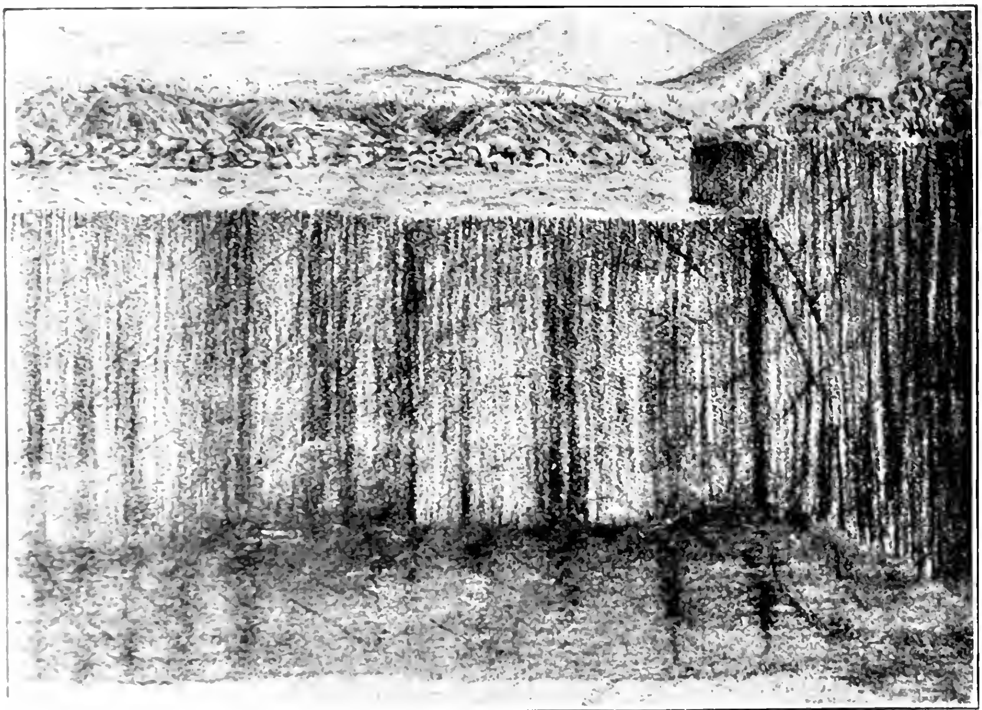

Fig. 3.

Sketch of the Southwest wall of the Danville Slate Quarry.

The cleavage is nearly vertical; while the original bedding planes can be seen dipping in folds towards the Southeast.

size, being stated, in the catalogue of the Paris Exhibition to be 150 feet deep, 300 feet long and 100 feet broad.

"The failure of the industry at this place was to a large extent due to the depression of the market at that time and a lack of capital necessary to carry out the work with modern equipment. Both these quarries are in contact on the west side with large masses of serpentine. The slates here found are continuous across the river St. Francis into Cleveland and Shipton. The oldest quarry in this belt is that on lot 6, range XV (Cleveland) formerly known as the Steele quarry, which was opened in 1854. No returns are to hand from this quarry under its new management, but the quality of the slate extracted is excellent in so far as yet tested. The output of the Danville quarry is as yet almost entirely confined to school slates, for which a ready market is obtained.

"Of all these slates it may be generally said that their quality is unsurpassed. Their chemical composition is very similar to that of the slates from Angers in France which have been in use in buildings in Montreal for considerably more than one hundred years."

The New Rockland, Melbourne and Steele quarries are so close to the contact of the serpentine intrusion that the slate is probably affected in some measure thereby. (Fig. 2) The Danville quarry, which appears to be in slate of the same original composition, is sufficiently distant from the contact to be probably unaffected by the intrusion.

The slate of Danville, judging from evidences now available, is softer and not so strong as that from the other quarries. The original bedding planes may be detected (Fig. 3) in places and in trimming the slate often "scallops" along them. On the other hand it seems to be an excellent material for school slates and other manufactures on account of its greater softness. Also the quarry itself is freer from quartz veins, which latter in the other quarries are more numerous near the contact with the serpentine than at a short distance from it.

Nearness to the contact is thus both a favourable and an unfavourable feature. Dykes and quartz veins are more numerous near it and where the alteration has been too great, the slate becomes "sharp" or is nearly a hornstone. On the other hand

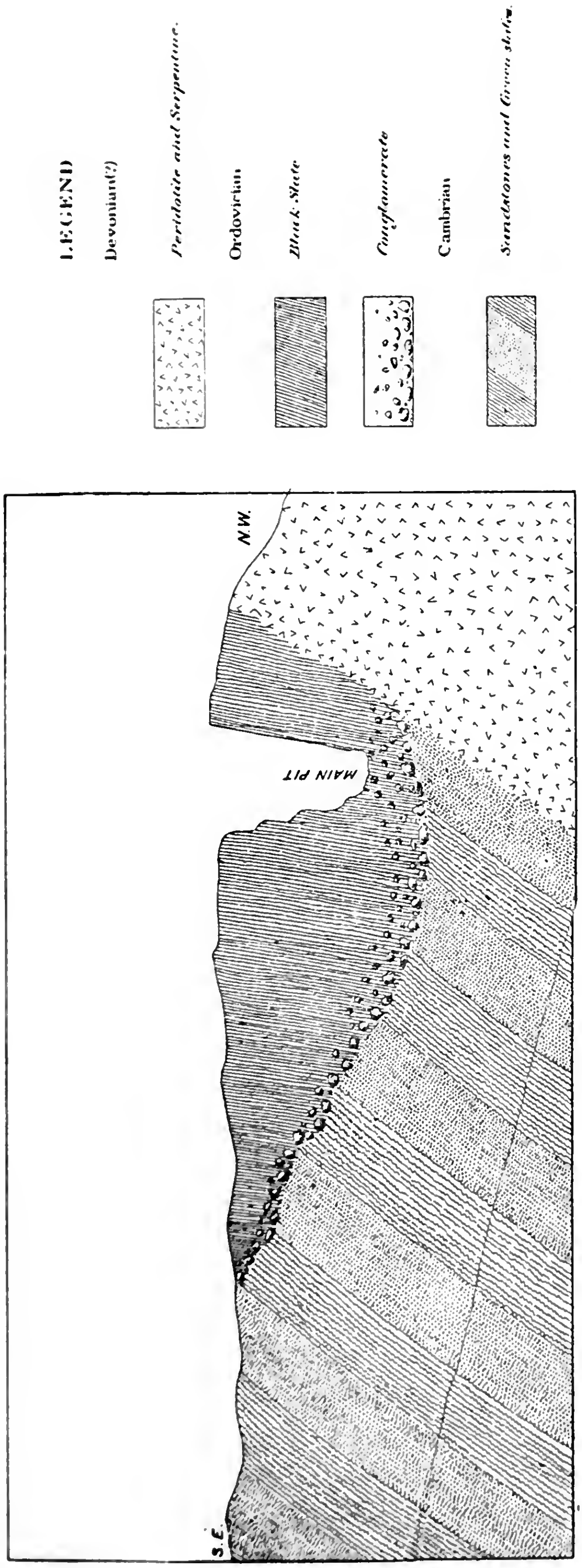

FIG. 2.
Diagrammatic section across the New Rockland slate quarry. This pit is about 200 feet deep.

slates beyond the effects of the contact have less hardness and strength. The most favourable location for slate seems to be in the outer part of the contact zone, near enough the intrusion to secure strong slate and far enough away from it that the spaces between the "flints" are sufficiently large to be advantageously worked.

The Melbourne, New Rockland and Danville quarries have been importantly productive; but the New Rockland only has been in operation during the past fifteen years. The major part of the production quoted on a subsequent page is to be credited to this quarry which has been in operation since 1868.

The production at present is wholly confined to thin roofing slate. The quality is well proven by its satisfactory use for the past forty years.

The following chemical analyses give a comparative view of the composition of several roofing slates of this series and one from Germany. The analyses are quoted from various reports of the Geological Survey:—

	New Rockland	Melbourne	Danville	Westbury	Lehesten, Germany
SiO_2......	65.39	64.20	61.80	65.85	67.57
Al_2O_3.....	15.97	16.80	13.48	16.65	17.30
FeO......	4.66	4.23	10.10	5.31	7.46
MnO.....	.39	.....	.74	.....	.....
CaO......	.67	.73	1.06	.59	1.16
MgO......	2.99	3.94	4.52	2.95	2.60
K_2O......	3.60	3.26	1.71	3.74	1.99
Na_2O.....	3.33	3.07	1.46	1.31	.....
H_2O......	3.26	3.40	4.86	3.10	4.62
	100.26	99.63		99.50	99.70

Slate has been worked unsuccessfully in Orford, range V, lot 2, in the county of Sherbrooke, where the slate appears to be very similar to that at Danville. The cause of the closing of the quarry some forty years ago has not been learned; but at that time the market demand was doubtless insufficient. As has been pointed out by Sir W. E. Logan, in a report of the Geological Survey on this district, published in 1863, a similar slate is well exposed in Brompton range V, lot 29, near the village of Bromptonville.

Both of these properties, though containing a soft slate, probably warrant investigation at the present time.

Other localities in which slates of this character occur are reported in range I, lot 14, the township of Halifax, county of Megantic, in Westbury, near the St. Francis river, and near St. Victor de Tring, in the county of Beauce.

On the south side of Long lake in the county of Temiscouata*, slate was exposed by a cutting on the National Transcontinental railway which promises to be of excellent quality and in ample quantity. Holdings have been purchased in the locality by Messrs. Frazer and Davies, the operators of the New Rockland slate quarry, and development operations, it is expected, will be inaugurated early during the present year. This locality is about 200 miles east northeast of the Danville slate quarry. It is not certainly known whether this slate is of Ordovician or of Silurian age.

Coloured Slates—Cambrian.—The slates usually referred to as "coloured" are red, green, mottled or purple, and are prevailingly coarser in texture and do not split as finely as the black slates. Coloured slates have never been extensively quarried in Canada; but in the United States a considerable production is maintained. Almost the entire production of the State of Vermont at the present time is obtained from the coloured slates of Cambrian age.

Details of Some Deposits.—Coloured slates are known to occur in several localities in the Province of Quebec and between twenty-five and fifty years ago, some of these quarries were productive to a small extent.

In Kingsey, range I, lot 4, county of Drummond, a quarry was opened in 1857 and closed two years later. The slate is principally purple although some green and mottled varieties appear. The colour is well preserved on slates split at about that time showing that they belong to the "unfading" class. The deposit is large and apparently the working conditions are favourable. A railway has been graded to the Grand Trunk railway at a point two miles from Richmond station, and four miles from the quarry.

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*Summary Report of the Geological Survey, 1908, p.

The following analysis of slate from this locality was made by T. Sterry Hunt in 1852 and the accompanying analysis of the Peach Bottom roofing slate of Pennsylvania, is added for comparison. These analyses are quoted from Kemp's "Handbook of Rocks."

	Kingsey	Peach Bottom, Penn.
SiO_2	54.80	55.88
Al_2O_3	23.15	21.85
FeO	9.58	9.03
CaO	1.06	.16
MgO	2.16	1.49
K_2O	3.37	3.64
Na_2O	2.22	.46
H_2O	3.90	3.39
	100.24	

On lot 26, range V, in the township of Acton, county of Bagot, the Rankin quarry was operated in 1875-6 and produced some quantity of red and green slate.

Coloured slates have also been opened on lot 18, range X, of Brompton and on the IVth range of Melbourne about half a mile, southeast of the New Rockland quarry in the county of Richmond, on the 2nd lot of the Xth range of Brampton in the county of Dorchester, on the XVth range of Garthby, lots 8 and 9, county of Wolfe, at Mawcook, near Granby, in Shefford county and at other places in the Cambrian rocks.

QUARRYING AND DRESSING.

The rock is quarried and cut down in benches in open pits, and after being assorted in the pit, material suitable for splitting is hoisted and sent to the splitting sheds. Here it is cut, split and trimmed to the sizes required or to which it is best adapted. Slate is bought and sold by the "square," that is in quantity sufficient to cover 100 square feet after allowance has been made for all overlapping. The usual thickness in Quebec is 3/16 inch. The sizes vary from 12"x24" to 6"x12".

In the coloured slate quarries of Vermont much of the roofing slate is split to a greater thickness—from ¼ inch to 1¼ inches. The price varies with the thickness, an increase of about $2.00 per square being allowed for each additional ¼ inch. Thus slates ¼ inch thick might be sold for $6.00 per square, whereas one inch slate would be worth as much as $12.00 per square. These thicker slates must be bored and counter-sunk to carry nails or bolts, while thin slates merely require to be punched.

Quarrying and dressing of slate involve handling a large percentage of rock waste. Even in the best deposits only slate that will split in a definite direction and may be cut to definite sizes can be utilized. In addition to the loss in trimming and splitting, breakage from the blasting of rock, which falls from the high benches to lower levels, must also be considered.

Again, slate once frozen, if not split while frozen, is valueless and necessitates the removal of a covering of sap rock every spring. The waste from these sources added to the large quantity of defective rock remaining to be removed reduces the percentage of slate recovered of the total rock handled to a very small proportion —probably between 5% and 10%.

REVIEW OF THE INDUSTRY.

Canada.—The only slate produced in Canada for some years has been obtained from the Eastern Townships of Quebec, where it has been continuously quarried since 1860. Nova Scotia, New Brunswick and Ontario have yielded slate at different times and promising developments are reported from British Columbia; but as far as can be learned there is no production from these provinces at the present time.

The following statements of the values of the production and imports of slate into Canada during the past twenty-one years are obtained from the annual reports on the Mineral Production of Canada by Mr. John McLeish, Chief of the Division of Mineral Resources and Statistics, Department of Mines, Ottawa.

Year	Production		Imports
1889	$119,161		$41,370
1890	100,250		22,871
1891	65,000		46,104
1892	69,070		50,441
1893	90,825		51,179
1894	75,550		29,267
1895	58,900		19,471
1896	53,370		24,176
1897	42,800		21,615
1898	40,791		24,907
1899	33,406		33,101
1900	12,100		53,707
1901	9,980		72,187
1902	19,200		72,601
1903	22,040		84,437
1904	23,247		86,057
1905	21,568		93,228
1906	24,446		112,941
1907	20,056	—9 months	95,520
1908	13,496		131,069
1909	19,000		135,221

Some slate has been exported during the above period; but the amounts have been comparatively small and so irregular that they may be neglected in considering the industry as a whole.

The year 1889 shows the greatest production and also the largest consumption in the history of the slate industry in Canada. The exports of that year amounted to $3,303 in value. In 1909, a year of small production the imports reached the highest, and the consumption the second highest place. The value of exports in that year was $612.

Broadly speaking production declined from 1889 to 1901, followed by a small and somewhat irregular advance. The imports decreased somewhat irregularly from 1889 to 1895, and since that date have steadily increased to the highest figures yet reached. At present, therefore, the production is scarcely more than 14% of the consumption.

Concerning the supply and demand Mr. McLeish remarks* "That there is a more extensive market in Canada than is supplied by slate from Canadian sources is shown by the following statistics of imports. The total value of the imports of slate in 1909 was $135,221 of which $71,914 was roofing slate and $34,085 school

*Op. cit.

writing slate. The imports of roofing slate, school writing slates, and manufactures of slate are chiefly from the United States. Some roofing slate is also imported from Great Britain, while slate pencils come principally from Germany and the United States."

During the past twenty years the prices of slate have advanced about in proportion to the increased cost of labour.

The duty on slate entering Canada is: 25% on roofing slate—not to exceed 75 cents per square; and 30% on manufactured slate.

In the schedule of the proposed Reciprocity Agreement, the duty on roofing slate is 55 cents per square.

All the Canadian output at present is used for roofing purposes.

The United States.—In the United States official returns for the year 1908 show a production valued at $6,316,817. Of this value $5,186,167 is in roofing slate and $1,130,650 in mill stock for various manufactures. Of this amount Pennsylvania produced nearly 62% or a value of $3,902,958; Vermont, 27%, or $1,710,491; Maine 3⅓% or $213,707. Almost the entire production comes from the eastern or Atlantic States. Vermont and Maine are the States most suitably comparable to Quebec in their geological conditions; and slate producing formations of both extend into Canada.

USES OF SLATE.

The principal uses of slate are for roof covering, writing slates, floors, electric switch-boards, billiard tables, blackboards, mantels, wainscotting, laboratory tables, lavatories, sinks and similar purposes. All the Canadian output and about 80% of the production of the United States are used for roofing. Slate was formerly manufactured for other purposes than roofing in Canada at the quarries of New Rockland and Danville; but this was discontinued some fifteen years ago. The consumption in Canada for 1909 was approximately as follows:—

Roofing slate	$ 90,914
School slate	34,085
Slate pencils	6,154
Manufactures	23,068
	$154,221

QUALITIES OF SLATE.

In a recent and exhaustive report on the slate deposits and industry of the United States, T. Nelson Dale* gives the following classification of slates:—

Classification of Slate.

1. Aqueous sedimentary.

(*a*). Clay slates; matrix without any or with but faint aggregate polarization.

(*b*). Mica slates: matrix with marked aggregate polarization.

(I). Fading: with sufficient $Fe\ Co_3$ to discolour.

(*a*). Carbonaceous or Graphitic.
(*b*). Chloritic (greenish).
(*c*). Hematitic and Chloritic (purplish).

(2). Unfading: without sufficient $Fe\ CO_3$ to produce any but very slight discolouration on prolonged exposure.

(*a*). Graphitic.
(*b*). Hematitic (reddish).
(*c*). Chloritic (greenish).
(*d*). Hematitic and chloritic (purplish).

II. Igneous.

(*a*). Ash slates.
(*b*). Dyke slates.

The slates of southern Quebec as far as known belong to the following divisions of the classification given above:

I. Aqueous sedimentary.

(*b*). Mica slates.

(2). Unfading (*a*) Graphitic—black—Ordovician.
(*b*). Hematitic—red—Cambrian
(*c*). Chloritic—green—Cambrian.
(*d*) Hematic & Chloritic—purple—Cambrian.

The black slates are strictly speaking phyllites, that is clay slates with a small percentage of mica. But as the strength of the

*Dale, T. Nelson and others.—"Slate deposits and slate industry of the United States;" Bull. U.S. Geological Survey, No. 275, 1906, pp. 5–6; also Annual Report U.S. G.S., Vol. XIX, 1897–8.

slate depends largely on the amount present, those slates which are strong enough to be useful are conveniently classed as mica slates, to distinguish them commercially from those so poor in mica as to be of little or no value.

The mica in these slates is not an original mineral but is developed chiefly from feldspar by alteration due to pressure perhaps accompanied by heat. It is in very minute scales, only a few thousandths of an inch in thickness; but the overlapping of these scales of mica is supposed to give to slates the elasticity that enable them to be split.

The above classification is based on certain general properties that affect the commercial value of slate; but it does not take into account all the features that determine its value. A degree of cleavage such that slate may be easily split to the required thinness, strength, freedom from injurious constituents and from excessive jointing are also important features.

Good cleavage is the first essential. Not only must there be a cleavage that will enable the slate to be readily split, but there must be an absence of cross or oblique cleavage generally called "slant" by the quarrymen, which not only interferes with the splitting, but still more lessens the strength of the slate.

Strength depends primarily on the degree of compression in a single direction with uniformity of composition and texture and in some cases on metamorphism by igneous contact. Recrystallization, especially the development of secondary mica, induced by pressure and heat, characterizes the strongest slates. Where the alteration has been insufficient, the slate trims unevenly or "scallops" often by breaking along original bedding planes.

Amongst injurious constituents carbonate of iron or carbonate of iron, magnesium and lime, cause discolouration when slates are exposed to the weather and so produce the "fading" slates. Iron pyrites rusts, causing spots and holes in slate. Magnetite makes slate less useful or even unsuitable for electric switchboards. Quartz veins have a similar effect even when small enough to not lessen the strength of the slate. Quartz veins, "flints" are a very common cause of poor quality in slate, and in any considerable quantity render it useless. Slates that are too siliceous (as from extreme metamorphism) even where no quartz veins are formed, become brittle and impossible to use. They are then known as "sharp" slates.

Porous slates of open texture, are unsuitable for uses that expose them to moisture, such as in making lavatories. They also shatter more readily if exposed to frost.

GENERAL CONSIDERATIONS AND CONCLUSIONS.

Deposits of slate that may be profitably worked are comparatively few and small. The overburden of "sap" rock which must be removed before uncovering slate of real splitting qualities and strength is generally deep—fifteen to twenty feet, at least, and in places much more. Great care must, therefore, be taken in selecting a location for a quarry and a considerable outlay of capital is necessary to develop such a property. Transportation is also a very important factor to be considered in the establishment and operation of a slate quarry.

Nevertheless the extension of roads and railways, the increasing cost of lumber, the introduction of the modern class of large steel-frame fireproof buildings in cities and the consequent use of thick slates—conditions that even twenty years ago were not obtaining—afford commercial advantages to the slate industry to-day that it did not previously enjoy.

Hence, speaking generally, the steadily growing market and the successful development of a large industry in similar geological formations in the neighbouring States of Vermont and Maine seem to warrant investigation by investors of the slate deposits of eastern Canada and especially those of southern Quebec.

DISCUSSION.

MR. FERRIER:—I have listened with peculiar interest to Mr. Dresser's interesting paper, and it has recalled many things I had almost forgotten since I was sent to make an examination of the New Rockland Slate Quarry in 1886. I notice that Mr. Dresser was exceedingly careful in his description of the peculiar terms employed by the quarrymen. I found that some of the terms used by the Welsh quarrymen were much more shocking.

I recognized after I had made my examination that much of the trouble in connection with the marketting of slate was due to a disregard to proper sorting, in consequence of which the material shipped was not always of an uniform and high grade character. I thoroughly agree that the zone from which the first-class material can be produced is a comparatively narrow one.

There is another feature to which Mr. Dresser did not especially direct attention, and a matter responsible for much trouble in the employment of slate for roofing. After purchasing slate for roofing purposes, one is at the mercy of the roofer. A careless workman may be the means of causing even the finest slate to show a bad record. With a shingle roof a defect is easily remedied; but this is not the case with slate.

I fully agree with Mr. Dresser's view that a great deal can and will be done to develop the slate industry in Canada, and bring about the more general utilization of slate as a roofing material.

DR. PORTER:—There was one point in Mr. Dresser's paper which seemed to be rather significant and that was the comparatively small size of the quarry which he described and apparently of the other quarries. Anyone who has visited the quarries in Wales or France, and some in Pennsylvania, will have noticed the enormous size of the workable areas, which eventually permit of installation and operation of large works. It would be interesting if Mr. Dresser could indicate whether in any parts of the Eastern Townships, there have been discovered slates of presumably good quality in such large masses to warrant the establishment of big enterprises.

MR. DRESSER:—The coloured slates occur in bodies great enough for large scale operations. The black slates of the best quality, however, are not as yet known in larger masses than those already worked.

MR. FERRIER:—As Mr. Dresser is much more conversant than myself with recent developments, I would ask him if he could bring out the point which I know was a serious one when I was connected with that investigation, namely, the difficulty experienced by local enterprises of competing with the cheaper grades of slate from some of the larger quarries abroad?

MR. DRESSER:—I could not say what grades of slate are being imported in competition. They seem to find, however, a very ready market and the work here is carried on at present in a rather small way. Meanwhile, the present duty on slate is 25 per cent., but not to exceed 75 cents per square. In the proposed Reciprocity agreement, this is amended to a flat rate of 55 cents per square. The importation comes largely from the United States, with the exception of a comparatively small quantity, valued at about $6,000, of slate for pencils, imported, I understand, from Germany. Our people, I believe, at present are unable to meet our own market requirements.

NOTES ON A DISCOVERY OF A TELLURIDE GOLD ORE AT OPASATICA AND ITS PROBABLE RELATIONS TO THE GOLD ORES OF THE PORCUPINE AND NEIGHBOURING DISTRICTS.*

By ROBERT HARVIE, JR., Montreal.

(Annual Meeting, Quebec, 1911).

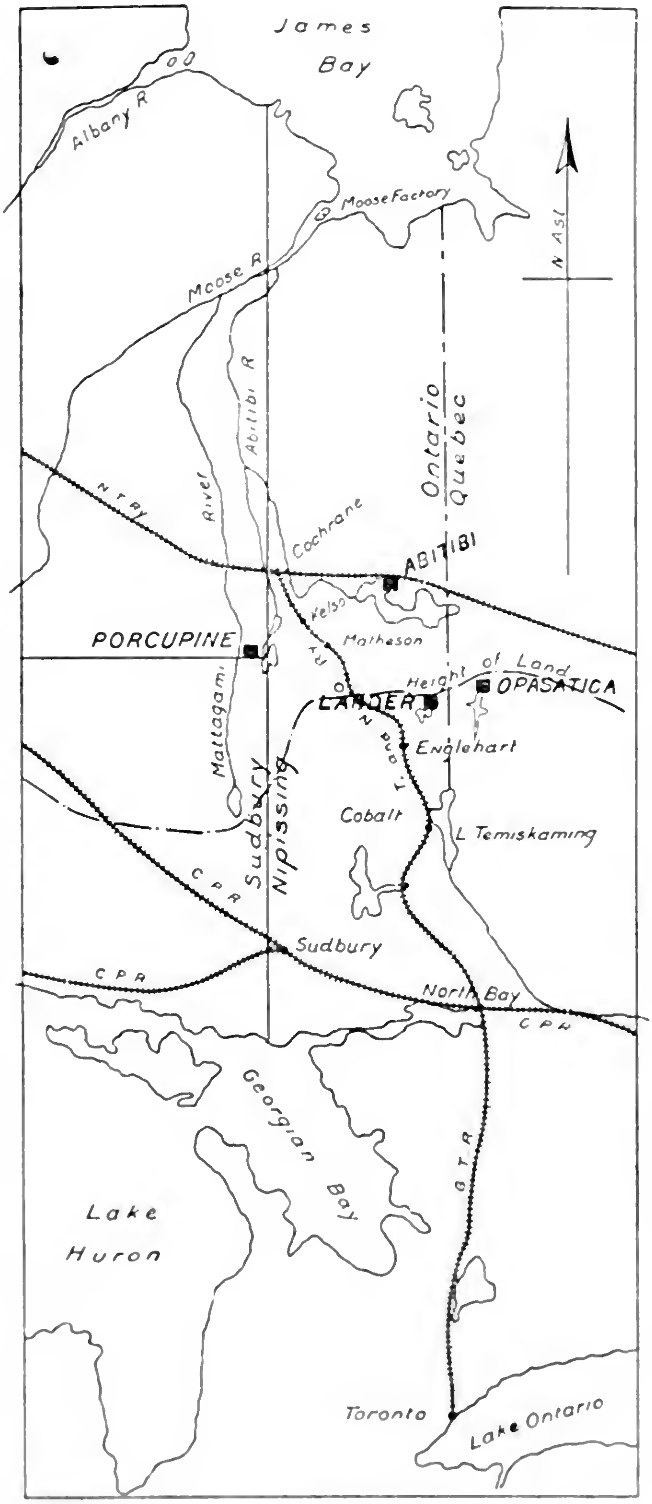
In the course of a short examination of the geological conditions obtaining in the Opasatica district, undertaken by direction of the Quebec Department of Mines, the writer observed certain new points of interest which it has seemed well to present in correlation with information obtained in the not far distant and evidently similar districts of Ontario, namely Larder Lake, Porcupine and Abitibi.

RELATIVE POSITIONS OF THE DISTRICTS.

The Opasatica district is in Quebec, on the height of land around the north end of Lake Opasatica, or about forty miles in a direction slightly east of north from the north end of Lake Temiscaming. From Opasatica, the Larder Lake district lies in Ontario about fifteen miles to the southwest, the Porcupine district is about 100 miles a little north of west, Abitibi is about fifty miles to the northwest. The relative positions are well shown in the accompanying plan.

As the general geology will not be discussed, this may be dismissed with the statement that the succession of Keewatin, Laurentian and Huronian is similar to that so frequently described for Cobalt and the other areas in this Temiscaming district.

*By permission of the Superintendent of Mines of Quebec.



KEY PLAN
Showing Opasatica, Larder, Porcupine, and Abitibi gold areas.

Opasatica.—The gold is associated with quartz-ankerite fissure veins, although in one instance the ore body is a rusty weathering dike of a dioritic rock cut across by very numerous small quartz veins which carry the values. The country rocks are of Keewatin or Huronian age. The largest vein observed averaged about two and a half feet wide in an exposure of one chain in length, and it may be said that all of those examined hold their width well. The gangue is quartz, partly massive, partly in free crystals, in both cases being commonly banded with ferruginous dolomite or ankerite and carrying sericite. In varying amounts pyrite, chalcopyrite, petzite and free gold also occur. In some instances chalcopyrite forms a large proportion of the vein matter, and the wall rock on either side is also heavily charged with sulphides, probably chiefly iron pyrite.

The values are obtained both from free gold and from the telluride petzite,[1] in which mineral there is about 25% of gold and 40% silver. The petzite was introduced later than the quartz and ankerite, being found in fractures in these minerals. The gold is chiefly in seams in the petzite. Petzite has a high metallic lustre of a steel grey colour, is heavy, has a low hardness, and altogether closely resembles galena, except that it lacks cleavage, and hence does not break into the cubes so characteristic of the latter. Owing to the small amount of work done so far, it is impossible to state what may be the relative importance of this telluride.

An assay of the pure chalcopyrite showed only half an ounce of silver and a trace of gold per ton; pyrite from the wall rock, gave only 40 cents gold per ton. Apparently then, both these sulphides are unimportant as carriers of values.

Larder Lake[2].—The gold is associated with irregular small quartz, or quartz and ankerite veins. The country rock is a rusty weathering rock consisting of ferruginous dolomite or ankerite, cut in a most complex manner by the gold bearing veins mentioned above. In most localities it contains a large amount of chrome mica or fuchsite, from which the rock derives its characteristic green colour.

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[1] In his "Preliminary Notes on Opasatica", Quebec Dept. of Mines, 1910, the writer referred to the *petzite* as *sylvanite*. This determination has since been revised.

[2] See M. E. Wilson: Summary Reports Geol. Survey of Canada, 1908 and 1909. Also R. W. Brock, Rept. of the Ontario Bureau of Mines, 1907.

Porcupine.—The writer has not yet had an opportunity of visiting the Porcupine district, but the recent articles by R. E. Hore* seem to give an excellent account of the conditions and his descriptions have been freely used for the present purposes.

The deposits at Porcupine are of various forms: single fissure veins, vein systems, large masses of irregular form,—locally called "domes," and bands of carbonate rock so closely intersected by a multitude of small veins that the whole mass has to be mined together.

The country rock is usually either pyritic grey schist or rusty weathering mixed carbonates, belonging to the Keewatin. Less often it is a Huronian conglomerate. Serpentines also occur in the district.

The rusty weathering carbonate rocks are similar to those occurring at Larder Lake and contain the same green mica. The gangue is chiefly quartz and ankerite. In general the quartz is milky white and vitreous, but where it has been exposed to the weather it is coated with iron oxides. For a few feet from the surface, streaks and patches of this secondary material are found filling small cavities and crevices, evidently left by the weathering out of the ferrodolomite or ankerite. Pyrite is rather generally distributed through the quartz, but not in any great quantity. Copper pyrite is also found in small amount and occasionally galena and zinc blende. The gold occurs chiefly free, not only in minute fractures in the quartz, but more especially in the rusty cavities. It remains to be seen whether this seeming abundance in the cavities is actual, or only due to an apparent concentration as a residual after the weathering away of the ankerite.

Though no actual results have been published it seems to be generally accepted that while 50% to 65% of the gold is free milling the remainder is held by the sulphides. On the other hand mention is also made that "good assays have in several instances been obtained from very unlikely looking "bull" quartz." No report has yet been made of the presence of tellurides and it is quite possible, even probable, that having been overlooked they will account for the presence of at least part of the gold in these veins.

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*R. E. Hore, Can. Min. Jour.; Oct., Nov., Dec. 1910; Jan. 1911; see also Notes on the "Map of the Porcupine Gold Area," by Ont. Bur. Mines, 1910.

Abitibi.—In the Abitibi district, in addition to other types of deposits, the rusty weathering carbonate rocks containing chrome mica, are typically developed, although on a small scale. The occurrence is quite close to a chromiferous peridotite.[1]

SIGNIFICANT FEATURES.

Enough has probably been said in the above brief descriptions to show certain resemblances between the deposits of these four districts. More particularly, free gold is found in quartz ankerite veins in or near occurrences of a rusty weathering carbonate rock characterised by containing a bright green mica, and while although so far tellurides have only been reported from Opasatica, still it seems probable that on closer examination they will be found in the other districts also. It is still more noteworthy that on these very same points an equally close parallel can be drawn with the deposits of the famous Mother Lode district of California. This will be done while considering a few special features in more detail.

Green Mica.—The beautiful bright green colour which the rusty weathering carbonate rock shows in so many places is due to a chrome bearing mica, fuchsite or mariposite. These minerals both contain chromium but in addition, mariposite also bears lithium. Mariposite is a very common mineral of the gold veins of the Mother Lode district in California.[2] Tests for chromium and lithium are readily obtained from the Canadian material and a rough comparison by the flame colouration test of the Larder Lake and Mother Lode materials shows the amounts of lithium to be comparable.

The Carbonate Rock.—The rusty weathering carbonate rock has been given various names according to the origin to which it has been ascribed. In the Mother Lode district where similar masses of carbonate are found, it is now generally accepted that they are due to the carbonation of a serpentine or peridotite, intrusions of which are found in the district. Peridotite hydrated and oxidised gives a serpentine; serpentine carbonated gives magnesite, siderite and quartz. This origin would seem to best

[1] Ont. Bur. of Mines, 16th An. Rept., Pt. I, p. 219; also 18th, pt. I, p. 270.
[2] F. L. Ransome, folio 63, U. S. Geological Survey.

explain the Canadian occurrences. Serpentines and peridotites are found at Porcupine and Abitibi, and are known to be widely distributed in the north country. Chromium as is well known is generally associated with peridotites so that the presence of the chromium bearing mariposite is explained and supports this view of the origin of the carbonate rock.

Ferruginous dolomites containing a chrome mica have been reported from Aird Island near the Spanish River in Lake Huron. This is suggestive of a wide distribution of these unusual rocks.*

TELLURIDE ORES AND THEIR SIGNIFICANCE.

Among the minerals found in the Mother Lode ore are numerous varieties of tellurides. Although by far the greater proportion of gold won has been obtained free, yet in a few mines the tellurides have yielded very important amounts. This fact affords another interesting point for correlation, since, as was mentioned above, petzite a gold-silver telluride is found associated with the gold at Opasatica.

At Opasatica the free gold is found chiefly in fractures in the petzite, so that apparently here also, as has proved to be the case in other deposits of telluride ores, the telluride has precipitated the gold, but the evidence yet obtained is too scanty to warrant assertion as to whether or not this has given a secondary enriched zone. At Cripple Creek, Colorado, in the zone of oxidation above the level of the ground water, the gold occurs free, having been largely left behind during the leaching of the tellurides. Below ground water level, the tellurides have not been leached, and not only do they still contain their original gold content, but in addition they have caught and retained any free gold passing down in solutions from the zone of oxidation, thus causing an important secondary enrichment. The presence of the tellurides at the surface at Lake Opasatica, indicates that the zone of oxidation has been removed by the heavy glaciation to which the district has been subjected. The present surface must therefore come either at the level of the zone of enrichment or below, but in either case, from this argument, it seems unwarrantable to

* Am. Journal Science, XXXIII, p. 284, 1887.

expect any great increase in values with depth, such as is regularly found to be the case in the mines of the Western States.

Tellurides have not been reported as yet from the other districts, but it has been reported from Porcupine that some apparently unpromising veins have yielded good assay values, which values may well be due to the presence of tellurides. In other veins the free gold at the surface has been found to continue in slightly increasing quantity down to a depth of two hundred feet. It is quite impossible that in this instance the zone of oxidation has *not* been completely removed, in which case an enriched zone may be encountered beneath.

It may be mentioned that this is not the first discovery of a telluride in Eastern Canada. Sylvanite has been reported as occurring associated with argentite, galena, chalcopyrite and quartz in the gold ore of the "Huronian Mine," near Lake Shebandowan in Western Ontario.*

While it has not been decided what is the source of the gold, and since moreover, in the Mother Lode district, it is found that in general the serpentine or its product the carbonate rock is unfavourable to values, it seems remarkable that although some at least of the veins are of Post-Huronian age, still the gold seems to be most typically associated with Keewatin carbonate rocks. No explanation has been suggested for this.

Assaying and Milling.—The presence of tellurides complicates both the testing and the treatment of the ores. The full value of the gold present cannot be judged from inspection or even by panning, because the amount contained in combination in the petzite is not shown by either of these processes. For this reason it is very essential that ores should always be tested by fire assay. Similarly when planning a mill, it must be kept in mind that simple amalgamation or cyandition will not recover the gold and silver values of the tellurides. The ore requires to be thoroughly roasted before employing these processes.

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* Geol. Survey of Canada, New Series, Vol. III, p. 13,H .; Vol. IV., p. 61 T.; Vol. X. P. 59, H.

ON THE NATURE OF SOME PORCUPINE GOLD QUARTZ DEPOSITS.

By Reginald E. Hore, Michigan College of Mines, Houghton, Mich.

(Annual Meeting, Quebec, 1911).

During 1909 several discoveries of gold in quartz were made in the vicinity of Porcupine Lake, Ontario, and subsequent development of the deposits has proved eminently encouraging. The possibilities of the region were clearly pointed out by Mr. E. M. Burwash and Dr. W. A. Parks in official reports published by the Ontario Bureau of Mines in 1896, 1899 and 1900. The more immediate factors leading to the exploration of the area, were the building of the T. and N. O. Ry., and the impetus given to prospecting by the discovery of silver at Cobalt.

The first official report on the gold discoveries is the report* of J. W. Bartlett, who visited the field in October 1909, for the Bureau of Mines. In March, 1910, E. T. Corkill of the same department visited the camp and made a brief report† of the work done. During the past summer, Dr. W. G. Miller, Mr. C. W. Knight and Mr. A. G. Burrows prepared a preliminary geological map of the area. This map, which was ready for distribution in August, besides showing the areal distribution of the chief types of rocks recognized, has useful marginal notes on the geological features. Two areas are described in some detail, some of the Timmins' properties by Mr. Knight, and the Dome and Foster claims by Mr. Burrows. Mr. N. L. Turner publishes the result of chemical analyses of some of the rocks, and Mr. Knight, notes on the microscopic character of some specimens. During the summer, Mr. R. W. Brock, the Director of the Geological

* B. of M. Ontario, Vol. XIX, 1910, pp. 11-12.
† B. of M. Ontario, Vol. XIX, 1910, pp. 120-123.

Survey, made a visit to the camp and has since published some notes on his observations. Mr. A. G. Burrows is now preparing a report* for the Bureau of Mines.

Several unofficial descriptions of the gold fields have appeared during the past year. In the *Canadian Mining Journal* may be found articles by Messrs. A. M. Hay, W. H. Spencer, H. B. Hatch, W. E. H. Carter, H. E. T. Haultain and others. In the *Mining World* and the *Mining Journal* are several articles by Mr. Alex. Gray. In the December number of the *Mining Magazine*, Dr. A. L. Simon has described some of the properties, and gives some general impressions. In the *Engineering and Mining Journal* Mr. P. B. McDonald has described the ore body at the Dome Mine.

The Bureau of Mines has published in recent years a number of separate reports on neighbouring districts, of value and interest in this connection. In the 13th and 14th annual reports, Mr. G. F. Kay and Mr. J. G. McMillan give general descriptions of the Abitibi country. In the 15th, Mr. H. L. Kerr describes the Mattagami River Valley. In the 16th annual report, Mr. R. W. Brock describes the Larder Lake district, Dr. Miller the Abitibi Lakes, and Mr. A. A. Cole notes on gold deposits of Night Hawk Lake. In the 18th report, Prof. M. B. Baker describes the Abitibi area, and in the same report Prof. A. P. Coleman discusses the glacial Lake Ojibway.

The geological succession at Porcupine as observed by Messrs. Miller, Knight and Burrows is as follows:—

1.—Glacial and Recent. Boulder and bedded clays, sand and gravel.

2.—Pre-Cambrian.—

a. Olivine diabase, intrusive into Huronian.

b. *Huronian*, conglomerate, greywacke and slate.

c. *Laurentian*, a medium grained biotite granite, intrudes Keewatin, but relation to Huronian unknown.

d. *Keewatin*, amygdaloidal basalts, quartz porphyries, felsites and serpentines, largely altered to green and grey schists. Also areas of jasper iron formation, which contain a considerable quantity of carbonate.

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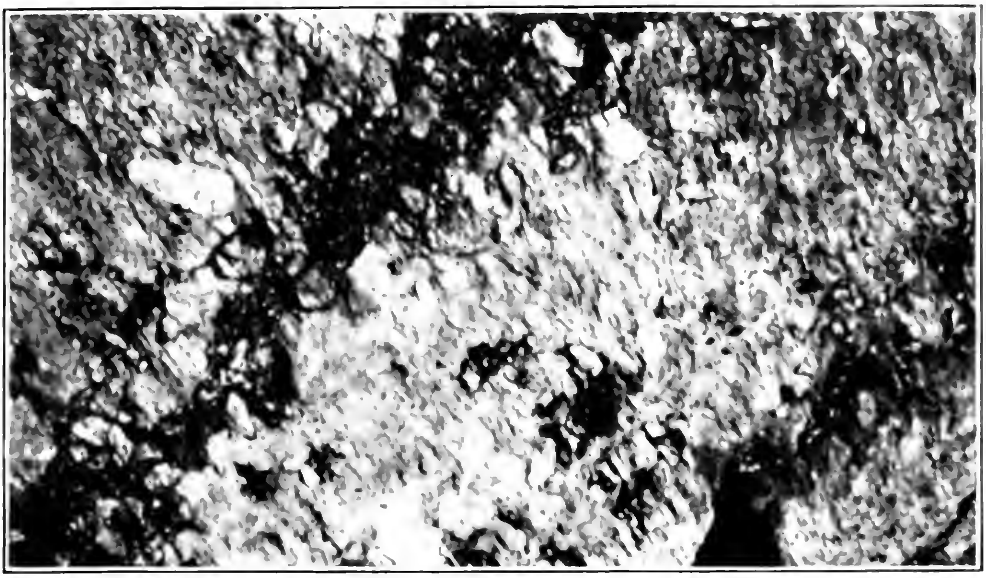
*A. G. Burrows' report was published in July, 1911.

Porcupine River. Looking up stream from Hill's Landing.

On the Porcupine winter trail, December, 1910

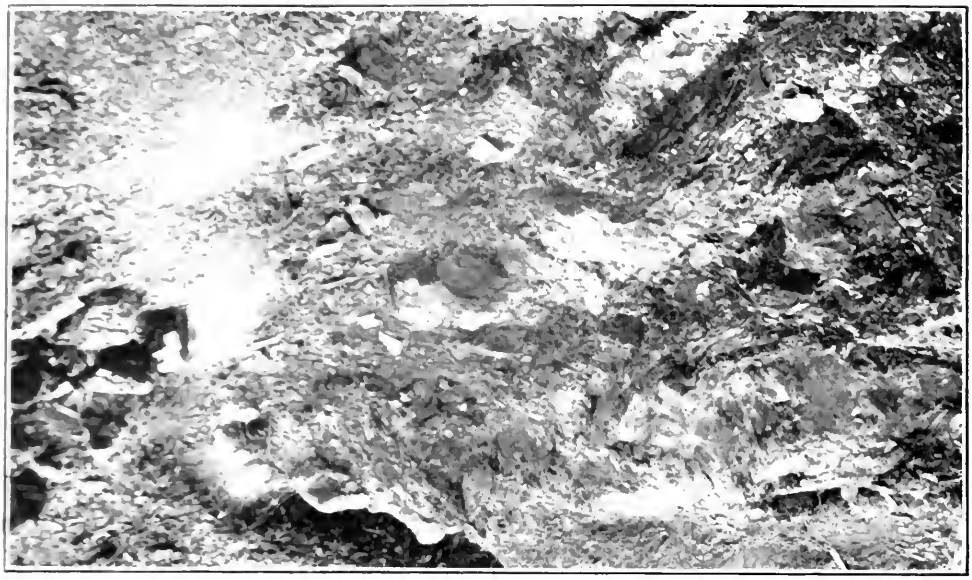
Dome Mine, showing Outcrops of white quartz, shaft head-frames, Diamond drill outfit and test mill.

Power House, test stamp mill and compressor buildings at Hollinger Gold Mine, Porcupine.



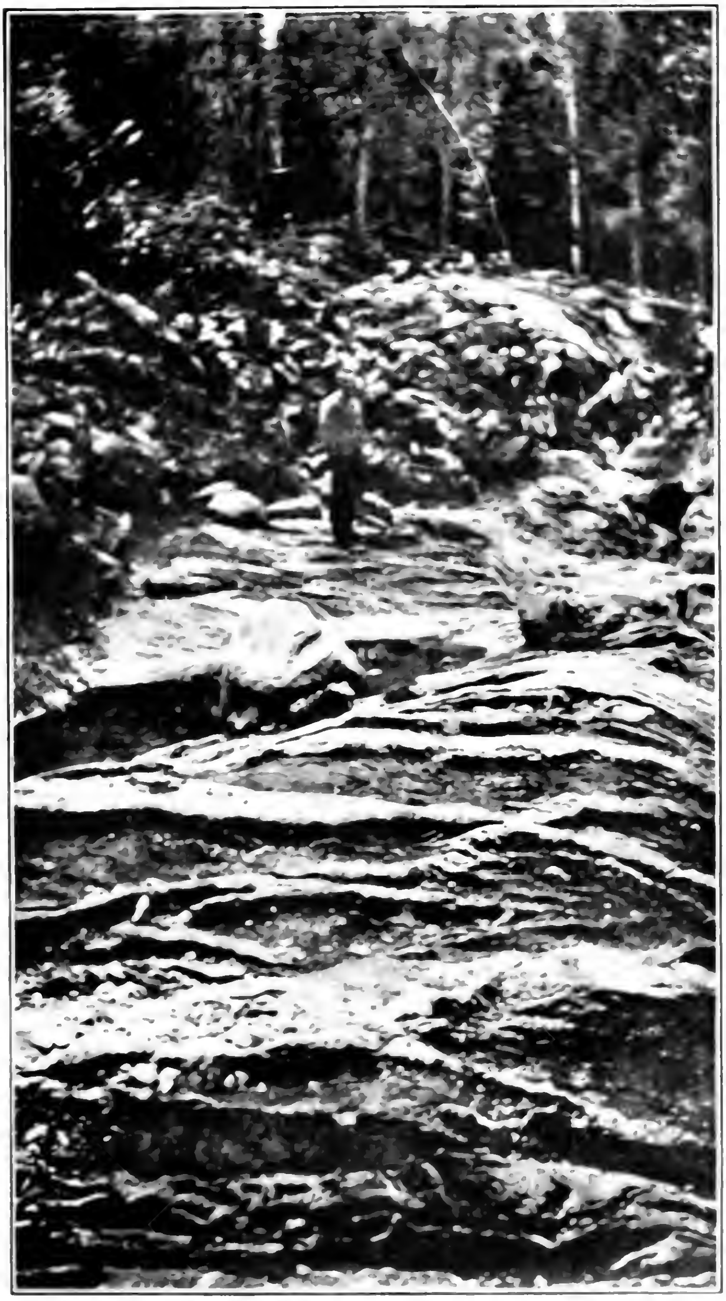
Conglomerate at Dome Mine, Porcupine

Dome conglomerate.



Quartz in grey schists, McIntyre Mine, Porcupine.

Quartz vein with stringers, Tisdale township.



Quartz ferrodolomite lode West Dome Mine, Porcupine. White quartz in rusty ferrodolomite

A system of quartz veins, Hollinger Mine, Porcupine.

Quartz in weathered and ferrodolomite wall rock, Rea Mine, Porcupine.

Quartz ferrodolomite lode, West Dome Mine, Porcupine.

Porcupine River near mouth. At right is island whose shape has given name to stream, lake and goldfield.

From this statement it will be evident that the geological features of the Porcupine area have much in common with the majority of other pre-Cambrian areas in Ontario and the Lake Superior States. Of nearby districts, the Larder Lake presents more analoguos features than does the vicinity of Cobalt.

Recently* the present writer has described some of the ore deposits in Tisdale township, and proposes here to present some observations on the general geology, and the microscopic characters of some of the ores and their wali rocks. The specimens examined microscopically are mostly from the Dome, Hollinger and Rea Mines.

GENERAL GEOLOGY.

The gold deposits at Porcupine are in what are believed to be pre-Cambrian rocks. The rocks in many respects resemble those at Lake Temagami and Larder Lake in Nipissing district, which have been more or less definitely correlated with similar formations around Lake Superior. On lithological grounds, therefore, and with no good evidence to the contrary, it is reasonable to assume that the Porcupine rocks are pre-Cambrian. Two formations may be distinguished—an older which is chiefly igneous, and a younger which is chiefly sedimentary. These two series are classed, by the writers quoted above, as Keewatin and Huronian. Most of the gold deposits are in rocks grouped above as Keewatin, or in the conglomerate which is grouped with the Huronian.

The chief properties in Tisdale township show gold quartz veins in the highly metamorphosed schistose rocks and not in the less metamorphosed greywackes.

KEEWATIN ROCKS.

The rocks which are classed as Keewatin include numerous types of igneous and sedimentary rocks, all of which have been much metamorphosed, and most of which are schistose. The greater volume is made up of igneous rocks and most of these

* Canadian Mining Journal, Oct. 15, and Nov. 1, 1910. Engineering and Mining Journal, Dec. 24, 1910. Mining and Scientific Press, April 29, 1911.

appear to be of volcanic rather than plutonic types. Varied colours including black, greenish, dark grey, light grey and yellowish grey are indicative of compositions ranging from basic to acid. Some of the dark coloured rocks appear to be altered basalts, and others are chloritic derivatives of andesites and porphyrites. The light coloured rocks are commonly sericitic products of acid volcanics, such as quartz porphyry. A remarkable feature of the wall rock of the gold quartz veins is the abundance of carbonates and sericite. At the Hollinger Mine many specimens are one half made up of carbonates. Part of the wall rock at the Dome mine is of similar type. At the Rea (Connell) Mine the north wall is almost completely composed of rusty weathering carbonates. The grey schist enclosing the Foster lode also contains much carbonate. These carbonate schists are mentioned here with the Keewatin volcanics, because it is quite possible that they may have been formed from igneous rocks by alteration of the constituent minerals and replacement of some of the products of alteration by extraneous material. That these carbonate rocks and some associated schists may be of sedimentary origin must also be considered. South of Tisdale there are outcrops of banded cherts and iron oxides characteristic of the Keewatin iron ranges. Such jaspilites are everywhere believed to be sedimentary, and with them are frequently found such ferruginous carbonates as those of the Porcupine gold deposits. There are no jaspilites, however, with the ferrodolomites in Tisdale township, and the carbonate outcrops appear as narrow bands enclosed in igneous rocks, in a manner which suggests that they have originated by replacement of such rocks. The Keewatin series then, while largely igneous, includes some undoubted sedimentary rocks—the iron formation—and some carbonates, which may be sediments. The carbonate wall rocks of the gold quartz veins, however, are probably replacement deposits.

Ferrodolomite.—These typically light coloured massive or schistose rocks are largely made up of carbonates, sericite and quartz. The carbonates contain variable percentages of calcium, iron and magnesium and weather rusty. The amount of iron is usually less than in normal ankerite. Some darker coloured associated rocks contain an abundance of chlorite and magnetite and are conveniently referred to as chlorite-ferrodolomite rocks.

It is possible that some of the greenish material in these rocks may be mariposite, but of the specimens examined by the writer, the pale green flakes appear to be sericite and the dark green ones a variety of chlorite. Some similar rocks at Larder Lake contain an apple green micaceous mineral, which more nearly resembles mariposite.

The ferrodolomites are commonly light grey, white or yellowish in colour, and weather red brown. In some cases they are disintegrated for a few feet from the surface and the red oxide leads to their easy recognition. Some outcrops, however, show little rust stain, and there are dark grey massive types that are likely to be confused with other rocks.

The analyses made by Mr. N. L. Turner show the carbonates to have a composition similar to those in the Keewatin formation in other localities. In various official reports, rocks of this type are called ankerite, ferruginous dolomite, dolomite and ferrodolomite. The latter term is to be preferred though the term ankerite is much in use in the district, and has been used for similar rocks associated with gold in California. Mr. W. H. Storms has recently* pointed out that most of the Californian "ankerites" should also be called ferrodolomites.

Chlorite-ferrodolomite rock.—Rocks of this type occur close to the main gold quartz vein at the Rea (Connell) Mine of the Consolidated Goldfields Co. Some specimens (see microphotos Nos. 1 and 2,) are almost entirely composed of chlorite and ferrodolomite, the latter mineral being in light coloured rhombohedra scattered through the dark green chlorite. In subordinate quantity are grains of quartz, minute scales of sericite and grains of black iron ores. The carbonate weathers rutsy, and some of the green chlorite rock near the vein is spotted with red brown altered ferrodolomite crystals. Other specimens show in addition to the above minerals, numerous remnants of altered feldspars, many of which show characteristic plagioclase twinning, while others show some orthoclase partially altered to sericite. The extensive alteration leaves the determination of the plagioclases somewhat in doubt. Apparently they range from oligoclase to andesine. Abundant chlorite and grains of magnetite indicate that the rock contained a considerable

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**Mining World.* Feb. 25, 1911, p. 448.

percentage of ferro-magnesian silicates; but the specimens do not show the original mineral—probably hornblende or biotite or both. One specimen shows pyrite surrounded by grains of ferro-dolomite. Another, in which there is but little magnetite, shows several spots of semi-opaque aggregates which are probably altered titanite. There is no residual glass in the rock. Some of the chlorite patches may have been derived from rock glass; but more likely the rock was holocrystalline.

This chlorite-ferrodolomite rock is therefore probably an altered fine grained feldspathic igneous rock, most likely an acidic andesite or porphyrite which has been permeated with and altered by solutions containing alkaline carbonates.

A few paces north of the Rea vein are rocks which are more highly feldspathic than that just described; but the alteration products are of similar character. The original ferro-magnesian minerals are not seen in the sections.

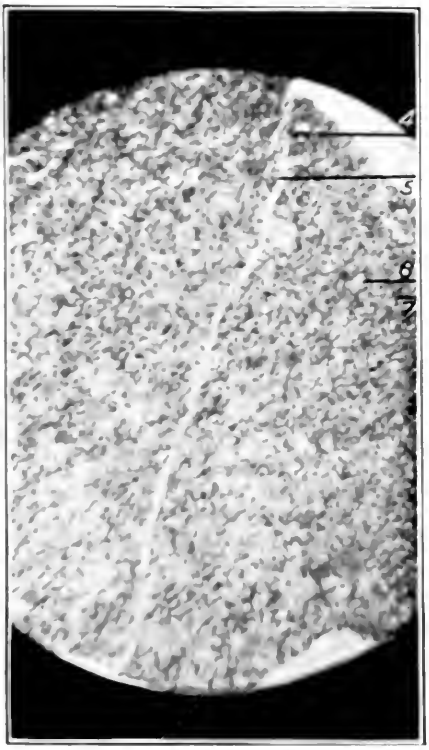
Sericite-ferrodolomite rock.—The wall rock of the main vein on the Hollinger (see microphotos Nos. 8, 9, 10 and 11) is for the most part a finely crystalline grey coloured schistose rock composed largely of sericite, carbonates and quartz. In one section, scattered through the fine grained ground of sericite and carbonates, are numerous larger, clear, ragged grains of quartz, occasionally in groups, but usually in isolated particles. The quartz grains are comparatively free of inclusions and show slight effects of strain. Some of the quartz, like the sericite and carbonates, is probably secondary; but these larger ragged grains at least, are probably the remnants of phenocrysts in the original igneous rock. The quartz has characters which are more common in volcanic than in plutonic rocks. There are also some patches of brownish white opaque substance, similar to that which results from decomposition of titanite. Pyrite is a characteristic constituent, often occurring in well formed crystals.

Another specimen has its quartz chiefly in the form of very minute particles. Among these quartz grains are numerous flakes of sericite arranged with their longer dimensions parallel and giving the rock its schistose character. Irregularly distributed through the fine grained quartz and sericite, are much larger particles of a carbonate. Pyrite and small particles of a light coloured opaque substance are abundant.

1

2

3



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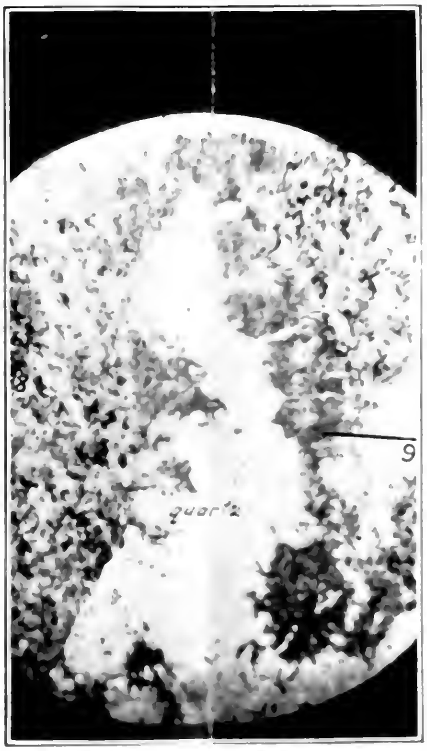


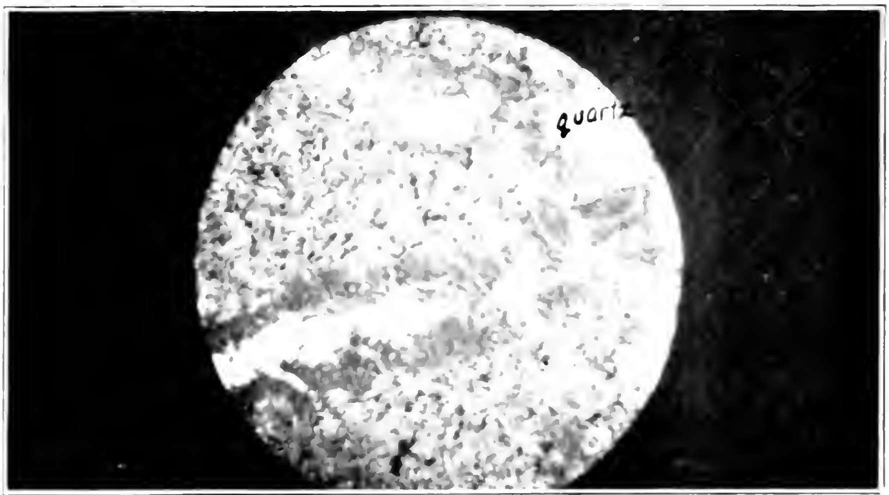
Microphotographs x 7 diameters
Wall Rock. Rea Mine.
Nos. 1 and 2 are chlorite-ferrodolomite rock.
Nos. 3 and 4 show quartz veinlets in ferrodolomite

White quartz vein in grey schists, Tisdale Tps., Porcupine, Ont. Shows veinlets of quartz penetrating into country rock.

Quartz ferrodolomitic lode, Foster Mine, Porcupine. White quartz in dark rusty carbonates.

An exposure of the Foster quartz ferrodolomite lode, Porcupine, 1910.

5



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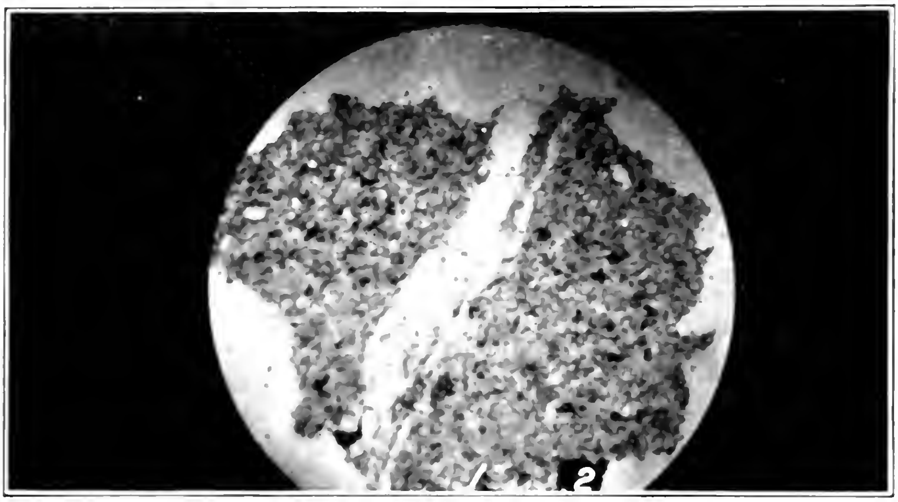
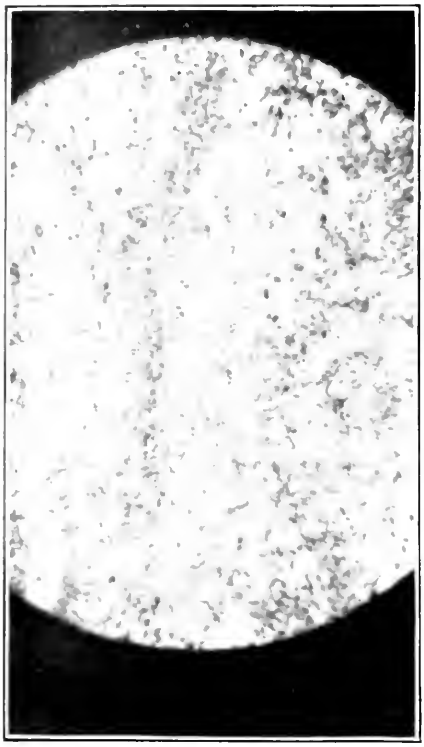


Rusty Carbonate — Pyrite

7

Microphotographs X 5 diam.
Quartz veinlets in ferrodolomite wall rock [illegible] Mg
No. 7 is same as No. 6 but [illegible] with [illegible]

8



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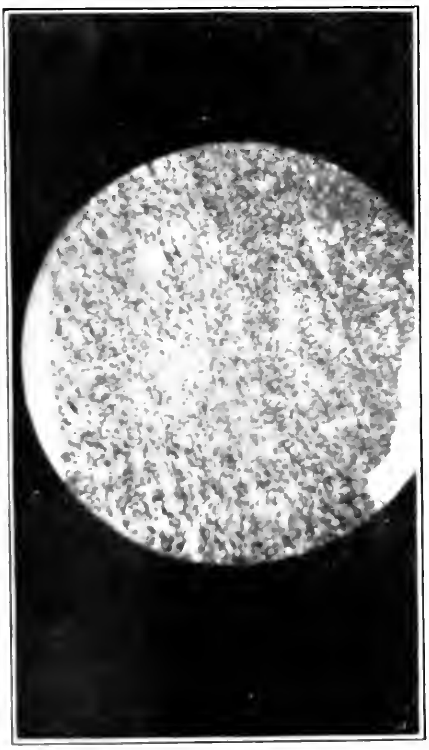

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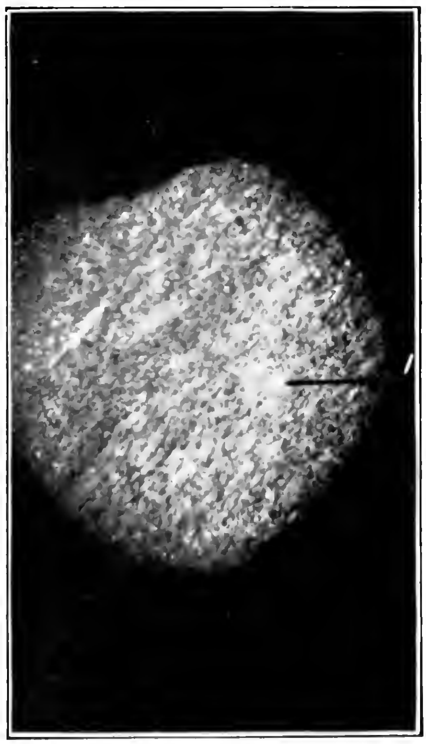
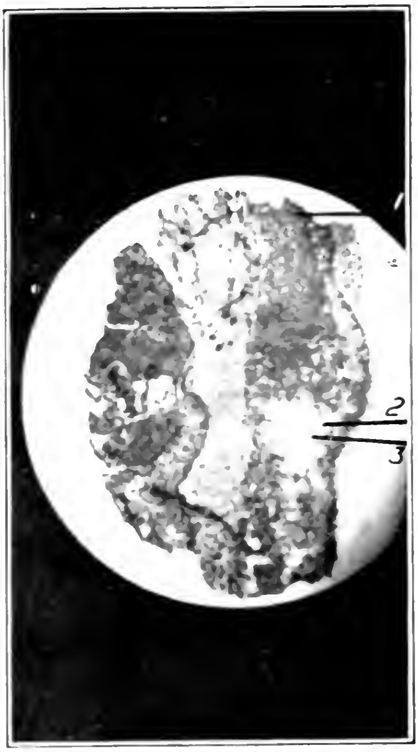


Microphotographs 8 and 9 x 7 diam. 10 and 11 x 5 diam.
Sericite Schists. Wall Rock, Hollinger Mine.
No. 11 is same as No. 10 with nicols crossed.
Chiefly sericite, carbonates and quartz.

12



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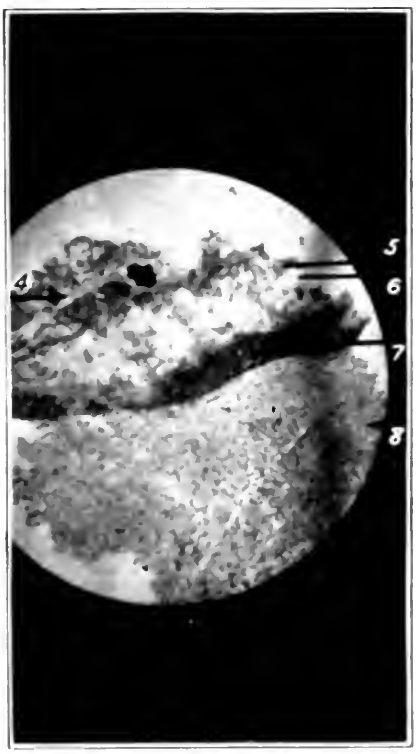
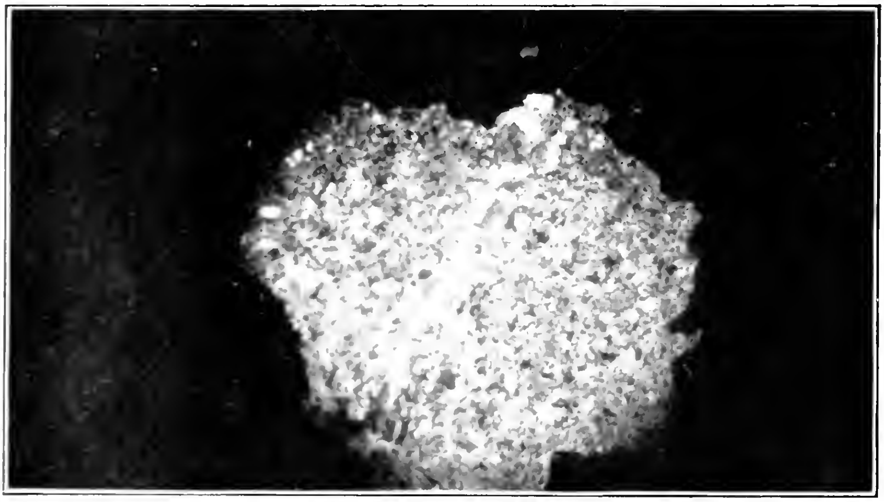


15

Microphotographs X 5 diam.
Wall rock, Hollinger Mine
Showing later formed areas separated by granular carbonate from earlier formed sericite schist
No. 13 is No. 12 with nicols crossed
No. 15 is No. 14 with nicols crossed

16

17



18

Microphotographs x 5 diam.
Gold in quartz, Dome Mine.
No. 17 shows No. 16 with nicols crossed.
No. 18 shows part of section to right and below part showing Nos. 16 and 17.

One specimen (see microphotos Nos. 11 and 12) shows bands of coarsely crystalline carbonate and quartz in fine grained quartz and sericite. The coarse quartz, which is remarkably clear and free from strain effects, fills spaces between earlier formed crystals of carbonates. This quartz is evidently secondary and younger than the carbonates. Another specimen similar to the last has a band of remarkably fine grained semi-opaque carbonates separating the fine and coarse grained portions. (See microphotos Nos. 13 and 14.)

The sericite schist at the Hollinger is made up (with the exception of part of the quartz), entirely of secondary minerals. What the original rock was is not shown by the specimens examined. Probably, as Mr. Knight has suggested, it was quartz porphyry. Whatever its nature, it was evidently leached by carbonate solutions. The resulting rock differs from that at the Rea mine chiefly in lower content, and in some cases entire absence of chlorite and magnetite. Such a difference would be the natural result if the rock replaced were a quartz porphyry instead of a rock containing a considerable percentage of ferro-magnesian minerals.

It seems probable, therefore, that the wall rocks of these two deposits have been produced, as Lindgren* remarks of the wall rocks of what he calls the "Pacific-coast type" of gold quartz veins, by the replacement action of waters distinguished by an abundance of carbonates.

HURONIAN ROCKS.—The rocks grouped above as Huronian include some very common sedimentary types, and one conglomerate that is partly made up of what is probably volcanic materials. The sediments are chiefly grey quartzite, greywacke and micaceous schists. They commonly show distinct bedding and are highly inclined. Such rocks are quite common in the Huronian in other pre-Cambrian areas, and these may conveniently be classed as Huronian sediments until the structural relations have been more definitely determined. It might be remarked, however, that there are localities in which sedimentary rocks such as these are found in the Keewatin series.

Dome Conglomerate.—The conglomerate is unusual in composition. It contains no appreciable amounts of distinctly grained rocks such as constitute many of the pebbles of most Huronian

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 * Trans. Am. Inst. Min. Eng., Vol. XXXIII, pp. 797, 1903.

conglomerates. The pebbles vary considerably; but are for the most part rather light in colour, grey and pink tones being common, and either wholly dense or else porphyritic with a dense ground mass. They appear on field examination to be of volcanic types ranging in composition from intermediate to highly siliceous. The pebbles are arranged in definite directions with their longer dimensions parallel, thus giving a decided schistose appearance. Only one well exposed contact of the conglomerate and sericitic schists was seen by the writer, and that showed no erosion unconformity. It is possible that the conglomerate belongs to the Keewatin series rather than to the Huronian. It seems, however, to overlie the Keewatin schists, and may have been formed early in Huronian times. A thin section of the grey coloured matrix shows scattered crushed grains of quartz and feldspar in a darker coloured matrix of quartz, sericite, ferrodolomite and magnetite. The carbonate is scattered irregularly through the rock, and in weathered specimens shows a red oxide border. The original character of the conglomerate is obscured, as in the case of the wall rocks at the Rea and Hollinger mines, by the replacement of original constituents by carbonates and sericite. It was probably originally a pyroclastic rock having a composition near that of quartz porphyry.

CHARACTERISTICS OF THE GOLD BEARING QUARTZ.

Like most occurrences of gold bearing quartz, the Porcupine ore is characterized by an abundance of pyrite. This mineral is commonly scattered through the white quartz, occasionally in isolated crystals, but more frequently accompanied by other minerals. Such aggregates commonly show numerous striated crystals of pyrite, a greenish sericite, a darker coloured chlorite and frequently grey ferruginous dolomite or other carbonate. In some cases there are brownish aggregates of small tourmaline crystals. In the country rock there is usually a greater abundance of pyrite than in the quartz.

The quartz is characterized by very numerous fluid inclusions. The original grains, usually 0.05 mm. to 1.0 mm. in diameter, almost invariably show strain shadows and many have been granulated. Evidently the quartz was subjected to very severe mechanical deformation.

Characters of auriferous quartz at Dome Mine.—Gold is most frequently seen in parts of the quartz near wall rock or pieces of enclosed rock. It occurs sometimes in isolated grains in clear quartz, but is usually with other minerals in minute crevices in the quartz. It is always in some way associated with pyrite, but the grains are not always in contact with the pyrite and in the sections examined only a comparatively small amount is intergrown with it.

The quartz is not uniform in grain and one may distinguish readily between part that is coarse and part that is fine. The coarser grains are commonly 0.5 mm. to 1.0 mm. in diameter, while the finer are about 0.05 mm. The coarse has numerous small cavities partially filled with liquid inclusions, and shows marked strain shadows; the fine has fewer inclusions and strain effects are not so marked. Fine grained quartz forms streaks running through the coarse grained. In some cases two coarse grains are separated by a row of fine grains, which have apparently been derived from the former by crushing. In one specimen an area, 1.0 mm. in diameter, of fine grained quartz encloses an isolated coarse grain 0.2 x 0.4 mm. in diameter. The finely crystalline has apparently been formed largely by granulation of the larger grains. The small particles are firmly cemented together and there was evidently some solution and recrystallization though the cement is not distinguishable under the microscope.

In the fine grained portions there is a notable absence of large fluid inclusions and evidently some such fluid was able to move among the fine quartz particles. The presence of fluid inclusions in the quartz indicates that it was hot when solidifying. The granulation of the quartz indicates that it was comparatively cold when crushed.

MODES OF OCCURRENCE OF GOLD IN DOME MINE QUARTZ.

1. *Gold completely enclosed in one grain of coarsely crystalline quartz*, e.g. One grain of quartz 0.5 x 0.8 mm. in the plane of the section completely encloses three isolated grains of gold. The small size of these gold grains makes it appear unlikely that they were not completely enveloped in the quartz, though there is a possibility that they were not. Another quartz grain 1.0 mm. in

diam. encloses three ragged grains of gold about 0.04 mm. in diam. and several gold particles 0.01 mm. or less in diam.

2. *Gold in spaces between grains of coarsely crystalline quartz,* e.g. One U shaped area of gold 2 mm. long and 0.02 to 0.06 mm. wide forms a ragged band between coarse quartz grains. It forms a border for two-thirds the periphery of one quartz grain—hence the shape. In several sections there is gold showing similar relation to coarse quartz grains.

3. *Gold in crystals and grains of pyrite.* e.g. One area of pyrite 0.5 mm. x 1.0 mm. encloses several irregular patches of gold, most of which are less than 0.1 mm. in diameter. Four of these gold grains are completely within the pyrite, while a much greater number are partially enclosed by the pyrite and partially by quartz. A second and rectangular area of pyrite 0.5 mm. x 0.1 mm. has along its middle portion five areas of gold. The string of gold particles continues from either end of the pyrite into clear quartz. Another specimen shows an area of gold 0.6 x 0.1 mm., which is four-fifths enclosed by pyrite, while the end projects into colourless minerals. The part of the gold not enclosed by pyrite is on one side in contact with calcite and on the other with a grain of quartz.

4. *Gold grains in calcite, completely or partially enclosed.*— A twinned individual of calcite 1 mm. x 0.5 mm. is enclosed chiefly by fine grained quartz, and one end is in contact with an area of pyrite 1 mm. in diameter. Around the edge of the calcite, and in immediate contact with it are nine distinct particles of gold. Within the calcite, and arranged in a string roughly following a cleavage direction are six grains of gold 0.02 to 0.03 mm. in diameter.

A second specimen shows an area of calcite 0.1 mm. x 1.0 mm. enclosing a number of small gold grains. This calcite is partially enclosed in fine quartz, but also fills a fracture in one large quartz grain. This same specimen shows gold in quartz with no calcite in contact.

Another specimen shows a grain of calcite 0.5 mm. in diameter, which wholly or partially encloses twenty ragged grains of gold. The gold is irregularly scattered through the calcite, but is mostly at the edges. The calcite is surrounded by fine quartz 0.05 mm. in diameter.

5. *Gold among grains of finely crystalline quartz.* e.g. One very irregular area of gold, 1 mm. long and varying in width from 0.02 to 0.1 mm., is almost completely enclosed by fine grained quartz, whose particles average 0.03 to 0.05 m.m. in diameter. That part of the gold not enclosed by quartz is in contact with calcite. It is noteworthy that most sections showing gold show also fine (probably granulated), quartz, and small amounts of calcite.

Wall rocks of Dome quartz.—The immediate wall rocks of the quartz specimens showing these modes of occurence of gold is a dark grey schist spotted with light coloured patches of quartz and with pyrite crystals. Under the microscope it shows a faintly pleochroic brownish aggregate, the constituents of which are not determinable, light coloured patches of sericite, quartz and ferrodolomite, and dark coloured areas of granular magnetite and well formed crystals of pyrite. Chlorite of the variety having characteristic Berlin blue interference colours occurs at the edge of light coloured areas.

Other specimens of wall rock include grey massive ferrodolomites and the conglomerate described above. The various specimens, while evidently originally different rocks, have in common a high content of sericite and carbonates. In this respect they are like the wall rocks at the Hollinger, Rea and Foster.

Characters of Auriferous Quartz from Rea Mine.

(Connell Claim).

The main vein at the Rea Mine is of milky white quartz and shows free gold with patches of pyrite and in minute dark coloured streaks traversing the quartz. A thin section of the quartz is chiefly made up of coarse grains—0.3 to 1.0 mm. in diameter. One patch of carbonate 0.3 mm. in diameter occurs enclosed in the quartz, and there are a number of smaller carbonate grains. The quartz shows very distinct strain shadows. Another specimen shows numerous grains of rusty weathered carbonate scattered between the quartz grains. A third section, and the only one showing gold, has much finely crystalline quartz in addition to the coarse grains. There are numerous greenish brown patches of finely crystalline aggregates of tourmaline. Quartz fills interstices between the better formed crystals in these aggregates.

One grain of gold, 0.07 mm. by 0.15 mm. and a second 0.03 in diameter occur at the edge of one coarse grain of quartz. The gold particles project into finer quartz, in which are reddish stains of iron oxide, apparently formed from alteration of pyrite. A third grain of gold 0.04 mm. in diameter, in another part of the section, is also at the edge of a grain of coarse quartz. None of the gold grains are in contact with pyrite, but are closely associated with it. None are in contact with the patches of tourmaline.

ORIGIN OF THE DEPOSITS.

It has been pointed out above that the character of the wall rocks suggests that they have been largely formed by replacement of older igneous rocks. It would appear that the solutions which acted on the rocks were characterized by alkaline carbonates. The association of gold quartz veins with such rocks suggests a common origin for the solutions which altered the rocks and those which filled the fissures with gold bearing quartz. Solutions of such a character may have come from magmas intruded near the surface, and giving off highly heated constituents which penetrated still nearer to though not reaching the surface. It would be of interest, therefore, to discover such masses of igneous rock as might have been formed from that magma.

Dr. W. G. Miller states that there are large masses of granite not far from Tisdale township, which intrude the Huronian, and believes the gold deposit to be genetically connected with them, and Mr. C. W. Knight in the same official report calls attention to the resemblance between the quartz veins and granite or pegmatite dykes. It is not unlikely that these gold deposits originated, as most others are generally believed to have originated, in the solutions given off when a molten magma was solidifying. As far as the writer is aware, however, there are not in the immediate vicinity of the deposits above described, any outcrops of intrusive igneous rocks which are likely to have been formed from the same magma as the gold-quartz veins.

From the character of the quartz with its abundant fluid inclusions, there can be little doubt that it was hot when first deposited in the fissures. Quartz with such inclusions is very characteristic of plutonic rocks, the inclusion of liquid (generally water or carbon dioxide) being evidently of common occurrence when solidification takes place at some depth. It has been pointed out by Judd and later by Van Hise, that there are cases in which the inclusion of water in cavities in quartz may be undoubtedly a secondary rather than a primary feature. This is not thought to be the case in the Porcupine gold quartz veins, however, as there is a marked difference in size and number of fluid containing cavities in the coarse and in the fine grains. Evidently the fluid was in the quartz grains before the deformation took place, and it was doubtless enclosed in the quartz grains when they crystallized at a comparatively high temperature and pressure. There are some cases, however, in which rows of inclusions are continuous through coarse and fine grains alike. Such inclusions may be of more recent origin.

It has been shown above that some gold is enclosed in individual grains of such primary quartz, while more fills interstices between quartz grains. There is little reason to doubt, therefore, that some gold was deposited simultaneously with the original quartz of the veins. The frequent association of gold particles with granulated quartz makes it appear not unlikely that the crushed zones in the vein afforded new channels for the movement of gold bearing solutions.

The pyrite, in part at least, appears to have been deposited from the same hot solution as the quartz and gold. It is noteworthy, however, that while the latter minerals are confined to definite limits, pyrite occurs scattered through the wall rocks more abundantly than in the quartz veins.

The relation of the carbonates to the quartz is not always evident. The ferrodolomite of the wall rocks is evidently older; but there are patches of carbonates in the quartz veins which may be younger.

The sericite of the wall rocks was evidently formed at the same time as the ferrodolomite. Undoubtedly much of it originated from potash feldspars in the igneous rocks; but its constant occurrence with the carbonates in the more basic rocks as well, indicates that the solutions emanating from the fissures contained considerable potassium in some form, as well as carbon dioxide and sulphides. It is remarkable that while these constituents found their way readily through the wall rocks, the silica was very definitely confined to the fissures, and did not play an important part in the meta somatic process.

In conclusion, the writer wishes to draw attention to the fact that the Porcupine gold quartz deposits are in many ways remarkably similar to the chief type of gold quartz deposit of California. Most of Lindgren's[1] arguments concerning the origin of the latter have almost equal force when applied to the chief deposits in Tisdale township. Naturally, therefore, in giving the above suggestions concerning the origin of the deposits in the new goldfield, the writer has been much influenced by the views of Dr. Lindgren. That a theory of origin worked out after many years' experience in one district should be found so readily applicable in another cannot but strengthen the belief that the theory will prove tenable.

Quite recently[2] Mr. John Stansfield has published descriptions of microscopic characters of ore and wall rocks from the Vipond Mine. He points out the abundance of fluid inclusions and the granulation of the quartz, and remarks on the presence of carbonates and sericite in the wall rocks, some of which are apparently altered basalts. He deduces that the quartz was deposited from a hot solution and was subsequently granulated. The Vipond deposits, therefore, are of the same character as those described above. At Larder Lake the wall rocks of the gold deposits show similar features to those at Porcupine, as also do those of gold deposits in the Opasatica district recently described by Mr. R. Harvie.[3]

More recently[4] Mr. W. H. Storms has described the case of auriferous ferrodolomites of California, and discusses their similarity to those of Porcupine.

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[1] Characteristic features of California gold quartz veins. Bull. Geol. Soc. Am., 1895; pp. 221.

[2] Canadian Mining Journal, Feb. 15, 1911

Quebec Mines Branch, Dec. 1910.

[4] Canadian Mining Journal, Sept. 1, 1911.

CANADIAN TELLURIUM-CONTAINING ORES.

D. D. CAIRNES, Ph.D., Ottawa, Ont.*

(Annual Meeting, Quebec, 1911).

During the past few summers the writer, while employed in northern British Columbia and southern Yukon, has had occasion to examine a number of quartz veins that contain rich gold ores in which various tellurides occur; and since tellurium-containing minerals seem to be particularly attractive to the prospector and are of somewhat rare occurrence, it is thought that, possibly, a brief description of these veins together with a compilation of some of the main, available facts concerning other known Canadian ore-deposits in which telluride minerals occur, may be of interest to members of the Canadian Mining Institute. Tellurium occurs as native and in composition with sulphur, selenium, bismuth, gold, lead, mercury, nickel and silver, yet the tellurides are the only mineral-compounds of gold that are known.

MINERALS.

The following tellurium minerals have been found and identified in Canada:—

Sylvanite, (Au, Ag) Te.

Hessite, Ag_2 Te.

Petzite, $(Ag, Au)_2$ Te.

Calaverite, Au Te_2.

Nagyagite, a sulpho-telluride of lead and gold, containing about 7 p.c. of antimony.

* By permission of the Director, Geological Survey, Department of Mines, Canada.

Altaite, Pb Te.

Tetradymite, approximately Bi_2 (Te, S)$_3$.

Tellurite, (Telluric ochre), Te 0_2.

In addition, a mineral, thought by Dr. Hoffman* to be native tellurium, was found at Long Lake, Greenwood mining division, British Columbia.

OXIDATION.

All these tellurides oxidize readily and give rise mainly to telluric oxide, tellurites or tellurates with bismuth, iron, and probably mercury, and native gold, silver, also, rarely, bismuth; the telluric oxide, also known as tellurite and telluric ochre, in its pure state is a soft (H. 2) white to yellowish mineral, but generally occurs mixed with other oxides, frequently those of iron, when a yellowish to reddish powder or coating results.

MINERAL ASSOCIATIONS.

With the exception of tetradymite, these minerals occur in Canada only in veins which may have been produced either by fissure filling or by metasomatic replacement or may owe their existence in a large degree to both agencies. The veins are found in a great variety of formations including various schistose rocks, granite, granodiorite, diorite, andesite, volcanic breccias, quartzite, slate, shale, and arkose; but with but one known possible exception they are all either in, or in the vicinity of, igneous rocks. In all cases, so far discovered, the veins consist predominately of quartz, but calcite and, rarely, ankerite and sericite occur as gangue minerals. Several varieties of tellurides are in many cases intimately associated in the same deposit and wherever one or more of these occur, native gold, silver and in places bismuth and copper are characteristic accompanying minerals, in addition to which, pyrite, chalcopyrite, and galena are present in many of the veins, and pyrrhotite, chalcocite, siderite, and zinc blende are found in some of them.

Sylvanite, hessite, petzite, calaverite, nagyagite and altaite

* Hoffman, G. C.,—Annual Rep. Geol. Surv. of Can., Vol. VIII, p. 10R.—12R, 1895–96.

are, in all the deposits so far discovered, minerals of primary deposition, so that their presence indicates a zone of unoxidized or at least incompletely oxidized material. The native gold, so commonly found associated with the tellurides, has in many cases been derived from these minerals by oxidation, when it is generally spongy and frequently has a brownish colour; where this origin for the gold can be proved, the zone in which it and the telluride occur together lies above that of the primary sulphides, and consequently (as the zone below ground-water level is reached *i.e.*, below the oxidized zone and the zone of secondary enrichment), the gold may be expected to cease to be free and to occur instead combined with tellurium.

Tetradymite is known to have been discovered at but two points in Canada viz:—at the Nickel Plate mine, Osoyoos mining division, and on the Roderick Dhu claim, Greenwood mining division, both in British Columbia. At the Roderick Dhu claim tetradymite occurs in a quartz vein like the other tellurides; but at the Nickel Plate mine it is found in contact-metamorphic rocks, and is probably also a primary constituent of the ore, although Mr. Camsell* who has described the occurrence, considers that possibly this mineral may be the result of secondary surface alteration.

USES AND VALUE.

Tellurium as yet has practically no technical use; consequently there is very little if any demand for the metal itself except for experimental purposes. A number of uses to which this metal may be put have recently been proposed, however, and concerning it, Edison† says:—"I have worked it to a considerable extent and I pronounce it a marvellous substance; I could use it in large quantities if it were cheaply produced."

Potassium tellurate is employed to a limited extent, however, in therapeutics, being used for night sweat of phthisis.

TREATMENT AND ASSAY.

To enter into a detailed discussion concerning the assaying and treatment of tellurium-containing ores, would be beyond the scope

* Camsell, C.,—"The geology and ore-deposits of the Hedley Mining district, B.C.;" Memoir, No. 2, Geol. Surv., Dept. of Mines, Can., 1910, p. 138

† Edison, T. A.,—Trans. Amer. Inst. Min. Eng., Vol. XVIII, p. 442.

of this short paper; but a few lines on this topic may not be entirely amiss, since a study of the literature dealing with these ores cannot fail to impress one with the fact that tellurium has a much more general distribution and is more commonly associated with gold than has been commonly supposed.

Treatment.—Ores in which tellurium occurs associated to any considerable extent with the precious metals have been a source of perplexity to many mill-men and metallurgists, particularly in American practice; in many of these cases, possibly in the majority of them, the tellurium has not been detected or if it has been discovered, its presence has been ignored with disastrous consequences. In milling processes, it is found that ores in which compounds of tellurium are prominent, are not susceptible to amalgamation or to the ordinary methods of hydraulic concentration. Concerning smelting operations Kustel* states that "not all tellurium combinations with gold, lose gold to a notable extent while roasting; but some do, and that up to a considerable amount, 20 per cent, perhaps even more." He also adds: "The loss is no mechanical one, occasioned by draft of the furnace, but principally by volatilization." The result of the various investigations from those of Plattner to the present, seems to be that in all ordinary oxidizing roasting of gold ores containing no tellurium that there is no loss of gold other than a mechanical one; but where ores are involved in which there is any appreciable amount of tellurium, there appears to be always a loss of gold by volatilization, in any operation involving the roasting of the ores or any of their products from which neither the gold nor the tellurium has been separated. Mr. F. C. Smith has made a careful investigation of such ores and in an excellent article† concerning them writes:—

"Careful experiment with such ores, especially where conducted at a reduction works handling large quantities of them, should not only finally avoid embarrassment from the presence of the tellurium, but even turn it to a profit." This indicates that the only objectionable influence tellurium in ores possesses is likely to be overcome; when this is established the discovery of this metal in an ore-deposit will be cause for unalloyed gratitude on

* Roasting of Gold and Silver ores," p. 57.

† "The occurrence and behavior of tellurium in gold-ores, more particuarly with reference to the Potsdam ores, in the Black Hills, South Dakota:" Tran . Amer. Inst. Min. Eng., 1896, Vol. XXVI, pp. 485–516.

the part of the owner, as tellurium is almost invariably an indication of the occurrence of gold.

Assay.—On the subject of the assaying of ores containing tellurium, Mr. Chas. A. Fulton, has published a very carefully prepared article* and according to him scorification of any kind is a very bad, and the crucible assay is the best method. The fire should be moderately hot, a large excess of litharge should be used, and a button of 20 to 28 grains should be obtained, which can be cupelled directly.

IDENTIFICATION.

The presence of tellurium is frequently overlooked partly because, in many cases, it occurs in very small amounts, and also because its determination is a somewhat difficult and laborious process in comparison with that of gold and silver. A small fraction of an ounce of gold to the ton of ore may be easily and accurately determined by dry assay; but a similar amount of tellurium, or other metal to be found by wet methods, calls for a refined analysis. A refractory character in ores, or even the recognition in the gold carried by them of the brown spongy appearance characteristic of gold derived from the alteration of tellurides, is sufficient to arouse suspicion as to the presence of tellurium. A further significant fact concerning ores containing this metal is that even when very rich, they often fail to show colours in panning

LOCALITIES.

Ores containing tellurides have been found in the following Canadian localities which are named in order commencing at the northwest and proceeding towards the southeast. On the accompanying map of Canada the positions of these localities are indicated by encircled numbers which correspond with those in the list given below.

Yukon Territory.

1. Wheaton River district, Conrad mining division, on—
   (a). The Gold Reef claim on Gold Hill.
   (b). The Buffalo Hump group on Mt. Stevens.

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* "The assay of telluride ores;" Jour. of Amer. Chem. Soc., 1898, p. 586-597.

British Columbia.

2. The Engineer Mines and vicinity, on the east side of Taku Arm, above Golden Gate, Atlin mining division.

3. Valdez island, Nanaimo mining division.

4. The Nickel Plate mine, Osoyoos mining division.

5. Near Osoyoos lake, Osoyoos mining division at the following points:—

(*a*) Northern end of Osoyoos lake (reported occurrence).

(*b*) On Kruger Mt., on western side of Osoyoos lake.

6. Olds Mt., Arrow Lake mining division, (reported occurrence).

7. Burton camp, Arrow Lake mining division (reported occurrence).

8. Long Lake camp, Greenwood mining division, on the following properties:—

(*a*) Jewel mine.

(*b*) Lakeview claims on the north side of Long lake.

(*c*) North Star claim, on the south side of Long lake.

(*d*) Enterprise claim, on the south side of Long lake.

(*e*) Roderick Dhu claim.

9. Olive Mable claim, Gainor creek, Trout Lake mining division.

10. 6 miles north of Liddle creek, Kaslo river, West Kootenay district (reported occurrence).

11. Pay Roll mine, ten miles southwest of Cranbrook, Fort Steele mining division.

Ontario.

12. Gold creek, Pine Portage bay, Lake of the Woods district.

13. The Huronian mine, near Jackfish lake, Moss township.

14. The Sudbury mining division, 2 miles south of the south-east corner of Musgrove township (reported occurrence).

*Quebec.**

15. The Opasatica district, Pontiac county.

Tellurium is reported to occur also in Newfoundland.

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* Tellurides also probably occur in the Porcupine area.

DESCRIPTIONS OF OCCURRENCES.*

In the following paragraphs, brief synopses are given of the available information concerning the tellurium-containing ores of the above mentioned localities, together with references to published descriptions of these deposits. An attempt has been made that the list of occurrences and references shall be as complete as possible, and it is hoped that members of the Canadian Mining Institute will kindly supply any omissions that occur.

1*a*. GOLD REEF CLAIM.†

The Gold Reef claim was staked in 1906, and was the first location made on Gold Hill in the Wheaton River district, Yukon Territory, situated midway between the Watson and Wheaton rivers and twenty miles in a westerly direction from Robinson on the White Pass and Yukon railway.

The ore on the Gold Reef property occurs in a vein in greenstone schists in the vicinity of intrusive grano-diorites, and is traceable for upwards of 1,000 feet, throughout which distance the vein has an average thickness of possibly four to five feet. The strike of the vein, in a general, way, coincides with that of the formation in which it occurs, so that the greater part of the quartz has been deposited along the foliation planes of the rock, and lies conformable to the enclosing laminæ; in places, however, the deposit cuts across the planes of schistosity for considerable distances.

The vein-filling consists predominantly of quartz which presents a dense, massive, appearance, and with the exception of occasional particles of pyrite, contains, in most places, practically

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* For an excellent general article on telluride gold ores the reader is rerred to:—

Kemp, P. L.,—"Geological occurrence and associates of the telluride gold ores:" Mineral Industry, 1898, Vol. VI, pp. 295–321.

† Cairnes, D. D.,—Sum. Rep. Geo. Surv. of Can., 1906, p. 27.

"Report on a portion of Conrad and Whitehorse Mining district, Yukon"; Geol. Survey, Dept. of Mines, 1908, pp. 18–19.

"Recent developments in southern Yukon:" Trans. Can. Min. Inst., 1907, Vol. X, p. 213–214.

"The Wheaton River district, Yukon." Geol. Surv., Dept. of Mines, Canada. In press.

no metalliferous minerals. A few widely separated pockets of rich ore, however, have been found, ranging in weight from five or ten pounds each to one of about six hundred pounds; this ore contains free-gold, sylvanite, hessite, petzite, and telluric ochre, the values usually representing hundreds of dollars to the ton; but so far the mineral has not been found in nearly sufficient quantity to pay for the development work undertaken on the vein.

1*b*. BUFFALO HUMP GROUP.*

The Buffalo Hump group consists of three claims located in 1906, and situated on Mt. Stevens in the Big Bend of the Wheaton river, Conrad mining division, Yukon Territory. On the Golden Slipper claim several tons of quartz were discovered, which was at first thought to form part of a vein *in situ*, but subsequent development proved it to be drift; the material, however, occurs near the summit of the mountain and appears to have been derived from the hill on which it is found.

The quartz, in addition to a small amount of disseminated galena, contains some native gold and sylvanite.

On the Surprise claim a quartz vein also occurs, which is as much as seven feet in thickness at one point and contains promising amounts of gold and silver, but in it no tellurides have been detected.

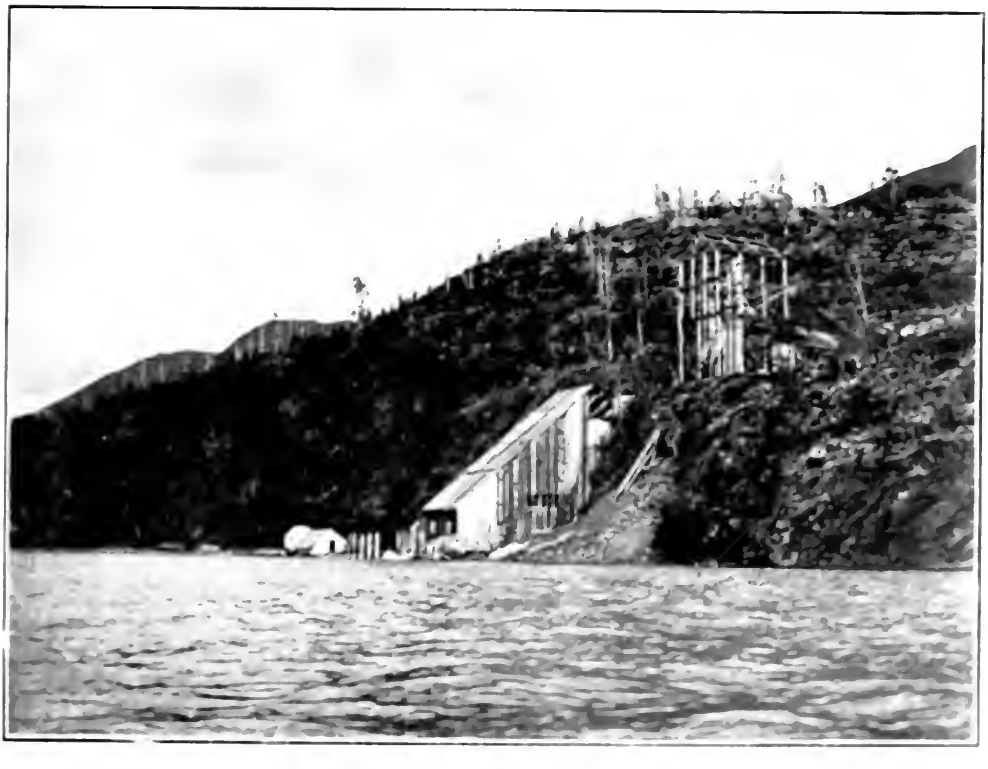
2. ENGINEER MINES† AND VICINITY.

The Engineer Mines are situated on the east side of Taku Arm, ten miles above Golden Gate, Atlin mining division, British Columbia. This property was first located in 1899, and although rich

* Cairnes, D. D.,—"Report on a portion of Conrad and Whitehorse Mining districts, Yukon": Geol. Survey, Dept. of Mines, Can., 1908, p. 19.
"The Wheaton River district, Yukon": Geol. Survey, Dept. of Mines Can. In press.

† Gwillim, J. C.,—"Report on the Atlin Mining district, British Columbia." Ann. Rep. Geol. Surv. of Can., 1899, Vol. XII, p. 45B.
"Atlin District": Ann. Rep. Surv. of Can., 1900, Vol. XIII, p. 55A.
Report of the Minister of Mines of British Columbia, 1900, pp. 760, 761 778; 1904, pp. 80–81.
British Columbia Bureau of Mines, Bulletin No. 1, 1910, pp. 5–6: Herbert Carmichael, Provincial Assayer.
Cairnes, D. D.,—Sum. Rep. Geol. Surv., Dept. of Mines, Can., 1910. In press.

Mt. Stevens, Conrad Mining Division. The arrow indicates the position of the Golden Slipper Claim, Buffalo Hump Group.



The Mill at the Engineer Mines, Taku Arm, Atlin Mining Division, B.C.

Looking up Thompson Creek toward Gold Hill. Conrad Mining Division. Yukon Territory. The arrow indicates the position of the Gold Reef claim.

gold-bearing quartz was found at various times in the early workings the, operations during the season of 1910, have resulted in the discovery of the rich ore in considerably greater amount than in previous years. The recent workings consist mainly of a few open-cuts, several hundred feet of trenching, and about fifty feet of tunnelling. A Joshua Hendry 2-stamp mill has been installed and was in operation during part of the season of 1910.

The ore occurs in veins in Upper Jurassic or lower Cretaceous shales, slates, and related clastic rocks in the vicinity of granitic and andesitic intrusives. The veins consist mainly of quartz associated with some calcite and varying amounts of intercalated and brecciated wall-rock, and contain as ore-mineral free-gold, a brass-yellow telluride (apparently calaverite), native bismuth, and pyrite.

Two deposits of quartz and brecciated and intercalated slate occur on this property, having exposed widths of 270 and 200 feet respectively, and exposed lengths but little in excess of these figures; but on account of the thick covering of superficial materials, neither their entire widths nor their lengths could be ascertained. Joining these two central masses from various directions, two sets of three and six veins respectively, have been discovered, which range in thickness from 2 to 40 feet. In addition, ten other veins from 1 to 50 feet thick were noted, which have not been traced into any central mass.

The larger veins and deposits are generally to some extent brecciated and contain considerable intercalated slate and other wall-rock; these all carry gold to some extent at least, as small particles were frequently found in them. The amount per ton of the gold, however, has not been definitely determined; but is known to be low in most cases, and the few assays that have been made have generally given results ranging from traces to about ten dollars per ton.

In four or five of the smaller, more thoroughly prospected veins, pockets or shoots of very rich ore have been found. These veins are composed almost entirely of quartz with some calcite, are from 6 in. to 4 ft. in thickness, and can be traced on the surface from 100 to 1,000; feet but even these have been but slightly explored. The pockets appear to occur prevailingly at points where the veins are intersected by cross-fissures; they vary considerably in size, some containing but a few pounds while others contain several hundred pounds, and the greater part of the ore has a value of from $1.00 to $5.00 per pound. It was ascertained during the summer of 1910, that much of the quartz in the veins between the high grade pockets, will pay to mill. The only body of rich ore of sufficient size to be termed a chute, so far explored, is in vein No. 1; this has an average thickness of from 1 to 2 feet, is at least 20 to 30 feet in length, measured along the strike of the vein, and has been followed downwards for thirty feet without any apparent depreciation in values. This chute might perhaps be better described as a portion of the vein in which pockets are more than usually present; but practically all the material so far obtained from it has been pay-ore.

The first 800 pounds of selected ore from this property that was milled during the summer of 1910, yielded 20 pounds 3 ozs. (Troy) of gold, the next 1,000 pounds, gave 21 pounds 8 ozs. (Avoirdupois), and it is claimed that the tailings in each case contain approximately 30 per cent to 40 per cent, of the original gold-contents; but the truth of this claim was not investigated. The ore taken from the various workings during the summer previous to September 1st., was valued at about $25,000 and from the part milled, $8,000 worth of gold bullion was obtained.

Tellurides are reported to have been found on other claims near Engineer Mines; but no specimens could be found by the writer when these properties were visited.

3. VALDEZ ISLAND.

Mr. H. Carmichael, Provincial assayer, Victoria, B.C., writes*: —"From Valdez island, B. C., we have news of a recent strike of copper ore carrying associated gold tellurides running half an ounce of gold per ton."

4. NICKEL PLATE MINE.

"Tetradymite is found sparingly in the upper part of the

* Carmichael, H.—Journal Can. Min. Instit., 1909, p. 452.

Nickel Plate mine"* which is situated in Hedley mining district, Osoyoos mining division, British Columbia. This mineral there "occurs in massive altered limestone which consists of garnet and epidote with much arsenopyrite," and is often found in association with free gold." Specimens of the ores from the Nickel Plate mine show crystals of tetradymite enclosing small particles of native gold."* This telluride "has apparently no connection with fissures" and as mentioned above, is most probably a primary mineral here as it is in the various veins in other places, but Mr. Camsell* also considers the possibility of the occurrence being the result of secondary surface alteration.

5*a*. OSOYOOS LAKE.†

Narrow quartz veins containing tellurides of gold and silver were reported to Dr. R. A. Daly† to occur in the diorite found at the northwestern corner of Osoyoos lake, Osoyoos mining division, British Columbia.

5*b*. KRUGER MT.

Messrs H. A. and G. A. Guess‡ observed hessite occurring with petzite, native gold, etc., in a vein composed of quartz and coarsely crystalline siderite, and the Calumet claim, Kruger Mountain, on the western shore of Osoyoos lake, in Osoyoos mining division, B.C.

6. OLDS MOUNTAIN.

Tellurides have been reported to occur on Olds mountain which forms the divide between the headwaters of Kettle river and Eight Mile creek which drains into Fire Valley. The deposits in this locality were examined in 1901, by the Provincial Mineral-

* Camsell, C.,—"The geology and ore deposits of Hedley Mining district, British Columbia"; Memoir No. 2, Geol. Surv., Dept. of Mines, Can., 1910. p. 138.

† Daly, R. A.,—"Geology of the western part of the international boundary (49th parallel)"; Annual Rep. Geol. Surv. of Can., 1902–03, Vol XV, p. 143A

‡ Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can., 1895–96, Vol. VIII, p. 12R.

ogist of British Columbia* who, however, was unable to find any of these minerals.

7. BURTON CAMP.

Mr. R. W. Brock† reports that some tellurides are stated to occur in Burton Camp which is situated at the east side of the lower end of the narrows between Upper and Lower Kootenay lakes, Arrow Lake mining division, B.C.

8*a*. JEWEL MINE.‡

The Jewel mine is situated in Long Lake camp, Greenwood mining division, Boundary Creek district, B.C. The ore on this property is described by Mr. R. W. Brock‡ as occurring in veins of from two to twelve feet wide, mainly at the contact between grey biotite-hornblende granodiorite and a green schist, but entirely in one or other of these formations. In the production of these veins both replacement and fissure-filling processes have been active. The ore consists of quartz carrying galena, pyrite, and chalcopyrite, and in the upper portions of the veins, some free gold, and "rich tellurides" are found.

8*b*. LAKEVIEW CLAIM.

Messrs. H. A. and G. A. Guess, indentified altaite "associated with hessite, fine to coarse native gold, thin plates of native copper and, apparently, native tellurium, in segregated quartz veins carrying chalcopyrite, pyrrhotite, and chalcocite, at the Lakeview claim on the north side of Long Lake, a small sheet of water some thirteen miles north-north-east of the mouth of Boundary creek,"** Greenwood mining division, Boundary Creek district, B.C.

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* Report of the Minister of Mines of British Columbia, 1901, p. 1130.

† Brock, R. W.,—Ann. Rep. Geol. Surv. of Can., 1898, Vol: XI, p. 69A.

‡ Brock, R. W.,—"Preliminary report on the Boundary Creek district, British Columbia;" Ann. Rep. Geol. Surv. of Can., 1902-03, Vol. XV, p. 127A.

**Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can., 1895–96, Vol. VIII, p. 10R–11R.

8c. NORTH STAR CLAIM.

Messrs. H. A. and G. A. Guess observed hessite "associated with native gold, chalcopyrite, pyrite and galena in a quartz vein, at the North Star claim"* on the south side of Long Lake, Greenwood mining district, B.C.

8d. ENTERPRISE CLAIM.

Messrs. H. A. and G. A. Guess, identified petzite "in association with free gold, galena, and pyrite, in a quartz vein at the Enterprise claim, on the south side of Long lake"† Greenwood mining division, B.C.

8e. RODERICK DHU CLAIM.‡

In 1895 Mr. Harry Guess of Midway, identified several tellurides, including tetradymite and altaite, in a twelve inch vein cutting a large granite-boss flanked by siliceous and micaceous schists on the Roderick Dhu claim, Long Lake camp, Greenwood mining division, British Columbia. Mr. Fowler also noted tellurides on this property.

9. OLIVE MABEL CLAIM.

The Olive Mabel claim is situated on Gainor creek, Trout Lake mining division, British Columbia, about 15 miles directly east of the head of the northeast arm of Upper Arrow lake, and according to Prof. Kemp's**descriptions, a body of quartz about two feet thick, which narrows to small dimensions at each end, has been opened on this property. The vein "contains much siderite some of which is decomposed, revealing considerable coarse free gold. Principally in the quartz, but to some extent in the siderite also, two tellurides are found. One is certainly nagyagite, as it

* Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can., 1895-96, Vol. VIII, p. 12R.

† Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can., 1895-96, Vol. VIII, p. 12R.

‡ Kemp, J. F.,—"Geological occurrence and associates of the telluride gold ores:" Mineral Industry, 1898, Vol. VI, p. 317.

**Kemp, J. F.,—"Geological occurrence and associates of the telluride gold ores:" Mineral Industry, 1898, Vol. VI, p. 317.

affords a mere trace of silver, if any, but much lead and gold. The vein lies in an extensive belt of argillites," which it cuts across, and no igneous rocks appear.

10 LIDDLE CREEK.

Mr. R. A. A. Johnston of the Geological Survey, Department of Mines, Canada, identified as massive altaite, a mineral occurring in a gangue of white sub-translucent quartz, in a specimen said by Mr. Ruecan* to have been found by him at a point six miles north of Liddle creek, Kaslo river, West Kootenay district, B. C.

11. PAY ROLL MINE.

The Pay Roll mine is situated to the north of the Moyie river, about a third of a mile north of the point where the trail up the river crosses Nigger creek. Here, according to Mr. McEvoy, a dyke of dark-green intrusive rock, resembling a diorite, extends northward, dissecting the flat-lying massive beds of gray quartzite. A small vein cuts across this dike and "showed," in a specimen examined by Dr. Hoffman,** "rust-stained quartz carrying a little telluride of lead (altaite) and some particles of free gold."†

12. GOLD CREEK.

Hessite is reported to occur‡ in lead-gray, plate-like masses with quartz and a little pyrite and chalcopyrite on Gold creek, Pine Portage bay, Lake of the Woods region, Ontario.

13. HURONIAN MINE.††

The Huronian mine, also at one time known as the Shebandowan gold mine, is situated in location H.1, in the township of

* Hoffman, G. C.—Ann. Rep. Geol. Surv. Can., 1892–93, Vol. VI, p. 29R.
** Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can. 1899, Vol. XII, p. 19R.
† McEvoy, J.,—Op. cit., p. 92A.
‡ Fifth report of the Bureau of Mines of Ontario, 1895, p. 105.
†† Hunt, T. C.,—"The geognostical history of the metals": Trans. Amer. Inst. Min. Eng., I, 331, 1873.
Engineering and Mining Journal, XV, p. 131.

Moss, Ont., and is about 70 miles in a direction a little north of west from Port Arthur. The rock formation here, according to Bureau of Mines' reports, consists mainly of interbedded talcoid, chloritic, dioritic, and a little dolomitic schist, siliceous magnetite, and massive diorite. A small intrusive area of granite sends an arm southwestward to within a short distance of the mine and is well exposed on Jackfish Lake. The ore occurs in a vein which is six to eight feet in thickness, of which two to five feet are mainly quartz, the rest being incorporated schist. The quartz carries pyrite, chalcopyrite, galena, zinc blende, sylvanite, and a little free-gold. Mr. F. C. Smith* says:—"The ore carried an inconsiderable amount of galena with iron and copper pyrites, argentite, hessite, sylvanite (or petzite), and probably altaite, the telluride of lead. Near the surface the ore showed considerable native gold, but this disappeared with greater depth. In some cases the tellurides occurred in irregular, bluish-grey masses enclosed in pure quartz; at other times they occurred as very dark brown scales filling small seams in the quartz. Samples of quartz from this mine, which showed no trace of metallic contents, but seemed to be saturated with the tellurides and resembled an ordinary piece of smoky quartz, have given upon assay as high as 902 ounces of silver and 34 ounces of gold per ton."

A ten-stamp mill was erected to treat the ore in 1883, and was run to some extent during 1884 and 1885, when work was suspended and has not since been resumed.

14. SUDBURY MINING DIVISION.

Mr. J. C. Nelson of Haileybury, Ont., showed a sample of ore

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*Smith, F. C. A proposed method for working tellurides: Trans. Amer. Inst. Min. Eng., XVIII p. 439.

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††Brown, T. M.,—Trans. Amer. Inst. Min. Eng., Vol. IV, 1875, p. 5.
Ingall, E. D.,—Ann. Rep. Geol. Surv. of Can., 1887–88, Vol. III, pt. II, p. 13H.
Hoffman, G. C.,—Ann. Rep. Geol. Surv. of Can., 1888–89, Vol. IV, p. 61T.
McInnes, W., —"Report on the geology of the area covered by the Seine river and Lake Shebandowan Map-Sheets": Ann. Rep. Geol. Surv. of Can., 1897, Vol. X, p. 59H.
"Report of the Royal Commission on the mineral resources of Ontario, and measures for their development": 1890, pp. 25, 115.
Bureau of Mines of Ontario, Second Annual Report, p. 191.
Bureau of Mines of Ontario, Fourth Annual Report, Pp. 38,40.
Bureau of Mines of Ontario, Fifth Annual Report, pp. 76, 80.
Bureau of Mines of Ontario, Fifth Annual Report, p. 106.

to Mr. R. A. A. Johnston, Mineralogist, Geological Survey, Dept. of Mines, Canada, which he claimed was obtained from a point in the Sudbury mining division, Ontario, two miles south of the southeast corner of Musgrove township. Of this specimen Mr. Johnston writes:—"A quartzose rock carrying small quantities of tellurium minerals containing lead, silver, and possibly gold."*

PORCUPINE AREA (?)

Tellurides probably occur in the Porcupine area, Ontario, as some apparently unpromising veins have yielded good assay returns ascribable, it is thought, to the presence of tellurides; further in refining gold bullion at McGill University from the Hollinger Mine, lot 11, con. 2, township of Tisdale, phenomena suggesting tellurium are believed to have been observed.

15. OPASATICA DISTRICT.

In the Opasatica district in the northern part of Pontiac county, Quebec, near the Ontario boundary line, on a claim owned by the Pontiac-Abitibi Mining Co., sylvanite occurs with native gold in quartz-ankerite veins cutting the Keewatin porphyrite and the Huronian breccia and associated dykes. The largest vein reported from here is about 2½ feet in thickness. The quartz is commonly banded with ankerite and carries sericite, pyrites, and chalcopyrite. The gold occurs both free and in combination with silver as sylvanite which is later than the quartz and ankerite.

From published accounts of the geology of the Porcupine country, Mr. Harvie† considers this district in geological characteristics must closely resemble the Opasatica and anticipates the discovery of tellurides there.

NEWFOUNDLAND.

Mr. Howley‡ mentions the occurrence of tellurium in Newfoundland.

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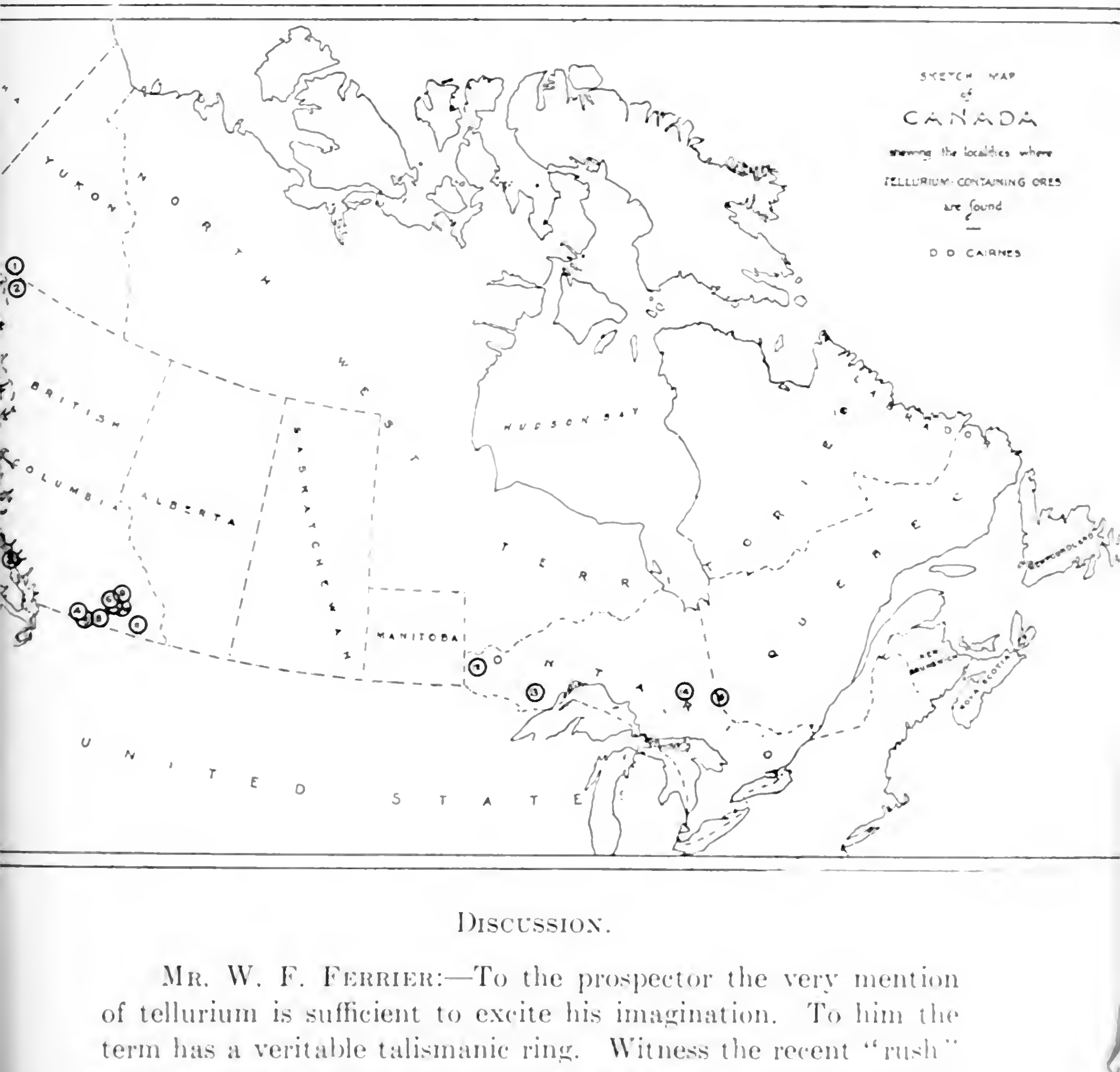
* Mr. Johnston's Office Notes.

† Harvie, R.,—"Notes on some gold-bearing veins in the northern part of Pontiac county, Quebec"; Quebec Mines Branch, Dec. 1910.

‡ Howley, J. P.,—Jour. Can. Min. Inst., 1909, p. 155.



Discussion.

Mr. W. F. Ferrier:—To the prospector the very mention of tellurium is sufficient to excite his imagination. To him the term has a veritable talismanic ring. Witness the recent "rush" southward of the Porcupine district; and again in earlier times to Cariboo.

Mr. T. Denis:—The likelihood of discovering tellurides of gold at localities in the Porcupine district would appear to be promising, since Mr. Harvie has recognized the presence of sylvanite on the Quebec side of the interprovincial boundary. Sylvanite, as is commonly known, contains about 24 per cent. of gold, and consequently it is small wonder that its reported occurrence in any one locality should be the signal for a stampede thither.

MR. J. MCEVOY:—With the uninitiated it is common to mistakenly associate tellurium with high gold values. At the Pay Roll mine, in British Columbia, to which reference has been made in the paper just read, the gold contents of the ore as represented by the selected specimen collected by myself, would perhaps have been from $800 to $1,000 to the ton; but in the case in question the tellurides were lead (altaite), and consequently had no association with the gold values in the ore.

MR. W. F. FERRIER:—Mr. Cairnes has alluded to the recovery of tellurium in ores. The saving of this product is not only feasible, but is now being accomplished, notably at Butte, Montana, and by the United States Smelting, Refining & Mining Company. At present, however, there is no market for tellurium.

DR. D. T. DAY:—In view of Mr. Ferrier's statement regarding the accumulation of tellurium for which there is at present no market, it seems to me that the establishment of a Government bureau in Canada to promote investigation towards ascertaining the possible uses of such minerals as tellurium would be most advantageous. I trust, for example, that every effort is being made to increase the uses of cobalt, of which this country is now producing so extensively. But when it comes to minerals like tellurium, you can afford to encourage the study. It is an important function in Canada to promote conservation in that direction. Investigation on these lines has been undertaken to an important degree by our own organisation in the United States. It is by no means so easy to find a market for a particular mineral, and I believe that the promotion of the utility for such a mineral can well be made a public undertaking.

THE PORCUPINE GOLD AREA OF NORTHERN ONTARIO.*

By A. G. BURROWS, Toronto, Ont.

(Annual Meeting, Quebec, 1911).

The area is situated on the Hudson Bay slope of northern Ontario, about 100 miles northwest of the Cobalt silver area. It is in latitude 48° 27′, and in elevation averages about 1,000 feet above mean sea level. The most important part of the area is in the township of Tisdale, and portions of the adjoining townships of Whitney, Shaw, Deloro and Ogden. In addition several outlying townships have attracted attention by recent discoveries.

The country from Night Hawk lake to the Mattagami river is one of low relief. Occasional ranges of hills reach an elevation of 150 feet; but generally abrupt changes in elevation are less than 50 feet. Often in a low area rocks outcrop only a few feet above the surrounding drift and are only a fraction of an acre in extent. Northwest, south, southwest and southeast of Porcupine lake the country is somewhat elevated and rock exposures are more frequent than in most of the area.

The area is for a considerable part drift-covered. These drift deposits consist largely of stratified clays, sands and gravels of post-glacial age and, in addition, there are patches of moraine material.

The compact rocks of the area may all be referred to the pre-Cambrian.

The Keewatin has a much greater distribution in the Porcupine area than the other members of the pre-Cambrian, and it is

*The author has prepared an official report on the geology of this area which is published as Part 2 of the Twentieth Report of the Bureau of Mines of Ontario. The notes here presented are a very brief summary of that report.

also of more importance economically, since it contains the greater number of the gold-bearing veins which have so far been discovered.

CHARACTER OF THE GOLD-BEARING DEPOSITS.

The occurrence of gold at Porcupine is associated with the quartz solutions which circulated through the fissures in the Keewatin and Huronian series. The irregular fissuring has produced a great variety of quartz structures, varying from the tabular, though often irregular or lenticular, vein which may be traced several hundred feet, to mere veinlets, often only a fraction of an inch in width and a few feet in length, which ramify through a rock that has been subjected to small irregular fissuring. This latter variety is well illustrated in the fissuring of ankerite bands, so characteristic of many of the gold deposits of Porcupine. Irregular and lenticular bodies of quartz often occur which may have a width of ten or twenty feet, but which die away in a distance of fifty feet. Again there are dome-like masses of quartz which are elliptical or oval in surface outline, but whose underground extension has not been examined closely. In some parts at least these masses can be seen in contact with underlying rocks at a low angle, which would suggest that they are broad lenticular masses which have filed lateral fissures in the country rock. The most conspicuous dome masses are those of the Dome property where the two larger are about 125 feet by 100 feet. A fissure may be vertical and regular at some points. At others it may incline at a lower angle to the horizontal or take on a more or less lenticular form.

DISTRIBUTION OF VEINS.

While gold-bearing veins occur over a wide area and are often isolated, it is seen, from a number of those already discovered, that they occur in groups along certain lines.

In these disturbed zones the country rock is generally schistose in character. At the Dome mine the disturbed area has a width of about 600 feet, in which there are numerous narrow quartz veins in addition to large irregular quartz masses.

Well defined, disturbed zones occur in the fifth concession of Tisdale. In this locality the main rock is a light greenish, fine-grained, rather massive greenstone. This greenish rock is itself not much fissured, but here and there through it are bands of rusty-weathering carbonate, which is generally schistose, striking east and west. I think that much of the carbonate associated with this greenstone is of secondary origin. It is possible that the shattering and fissuring of the greenstone in an east and west direction may have caused a deposition of migrating carbonate solutions, partly filling fissures and partly replacing the greenstone. These carbonate bands were later fissured, and gold-bearing quartz solutions deposited in them. The fissures of the carbonate is generally irregular, and hence we find veins with steep or low dip striking with the schist and across it. This irregular series of veins is seen at the Crown-Chartered and Armstrong-McGibbon properties. Where the veins are small, it becomes necessary to mine both the carbonate and the intersecting quartz veins. Gold often occurs in the carbonate near the contact with the quartz veins, as well as in the quartz.

DISTRIBUTION OF THE GOLD.

While the quartz is considered to carry the gold, it was noted at many properties that the metal occurs in greatest quantity along certain lines which gives a streaky character to the ore. On the surface these streaks are rusty due to the oxidation of pyrites, while at depth they are dark gray or greenish in colour.

Thin sections of quartz from the main Hollinger vein show grains of quartz with irregular outline, which often contain liquid and gas inclusions. There has also been much secondary pressure, indicated by strain shadows or wavy extinction, and along lines of slip or fracture planes there has been much crushing of the quartz to finer grains. In these crushed areas are secondary minerals like calcite, sericite, etc., while iron pyrites is also present in cubical form and has evidently crystallized, subsequent to the crushing.

Some thin sections from the Rea mine main vein also show much secondary crushing along lines. Calcite and sericite are present in the crushed quartz generally in linear arrangement.

and in addition there are several rough crystal outlines of free gold which were formed subsequent to the crushing.

These fine dark streaks may have resulted from a solidification and shrinkage of the quartz forming filmy cracks, which may have become slip or crushing planes along which the richer gold-bearing solutions were deposited at a later period.

These minute dark streaks in the quartz are frequently slickensided, and this character may often be seen in hand specimens, as from the Rea or Vipond mines.

It should be noted that where cracks or fracture planes have been produced in a quartz vein and subsequently filled by minerals from solution, secondary quartz can be distinguished with difficulty, if at all, from the original quartz. Hence it is not always possible to say whether visible gold in such a vein occurs in the original or in secondary quartz.

Carbonates of lime, magnesia and iron occur with the quartz in practically all the veins in the area. This material may have been absorbed from the wall rock, which is frequently dolomite or rock impregnated with dolomite or calcite. Fragments of country rock are often included in the veins. Veinlets of clear calcite occasionally cut the quartz veins.

The distribution of the gold is generally irregular, occurring along one or both walls, while other portions of the veins may be very low grade. Most spectacular showings occur on many properties, but these are limited to portions of the veins. Considering the irregular character of certain veins and the quantity of country rock which will need to be mined, the ore must be considered low grade.

Iron pyrites occurs in massive and crystallized forms, somewhat sparingly in most of the veins. Cubes of pyrites are frequently abundant in the enclosing rocks, especially where sericitic or dolomitic schist occur. A sample of cube pyrites was separated from the schist, obtained from a shaft of a principal property, and an assay gave a gold content of $10.40 per ton.

Copper pyrites, galena, zincblende and pyrrhotite are found in some veins in very minor quantity. Sulphide of silver, argentite, occurs in association with the gold on the Powell property in Deloro township.

The ore is largely free milling, while the concentrates should be amendable to cyanide treatment.

SILVER AND GOLD DEPOSITS ON THE WEST FORK OF KETTLE RIVER, B.C.

By L. REINECKE, Ottawa.

(Western Branch Meeting, Grand Forks, May 1910).

The following is a brief description of the more striking features of the silver-lead deposits on Wallace mountain and the gold-silver property at Carmi, on the West Fork of Kettle River.

Wallace mountain lies just east of the little settlement of Beaverdell, on the West Fork and is situated 25 miles from the junction of the West Fork with the main Kettle River, and 45 miles by road from Midway on the International Boundary. Carmi lies five miles up stream from Beaverdell.

Claims were first staked on Wallace mountain in 1889. These, however, were allowed to lapse, and active prospecting was not commenced until 1896. In that and the following year the more important claims on Wallace mountain were located. Between 1896 and 1900 much prospecting was done along the West Fork and in the country to the east of it. The remains of several townsites in the valleys, and numerous prospect holes in the hills, are indications of the lively interest taken in the district at that time. The only serious development work following this activity was that undertaken on the Carmi mine in 1899, and on Wallace mountain in 1900. Mining on a small scale has been prosecuted on Wallace mountain from 1900 to the present date. The Carmi was worked between 1899 and 1900 and again in 1904. Operations have since been suspended.

South from Carmi and Beaverdell, the valley of the West Fork has the U-shape, flat bottom and steep sides of a typical glacial valley. The gradient of the main stream is low—perhaps from 25 to 40 ft. to the mile--and so are the gradients of the lower reaches of Beaver and Wilkinson Creeks, its main tributaries. The hilltops around Beaverdell are from 1,500 to 2,000 ft. above the valley floor. With the exception of a few rugged tops, remnants of a volcanic plateau, the valley trenches are the most noticeable feature of the topography of the district. The hills are, in general, broad, flat-topped ridges thickly covered with timber. Outstanding points readily recognized from different directions are few, and this adds greatly to the difficulty and cost of a topographic survey of the district.

Timber is still plentiful along the valley. Yellow pine grows in the bottoms, while fir and tamarack are abundant on the higher slopes. Great patches have, however, been destroyed by fire, and there will be further considerable destruction, unless some efficient system of fire protection is adopted.

A well built waggon road connects Beaverdell and Carmi with the Canadian Pacific Railway at Midway. The mines on Wallace mountain are reached from Beaverdell by a switch-back road of remarkably low gradient.

Silver-lead Ores.—The silver ores on Wallace mountain occur in a series of fissure veins in granodiorite.

An extensive mass of granodiorite underlies the West Fork from a point about 8 miles above Beaverdell and for some distance to the south of that place. This is the country rock on Wallace mountain. It is cut by narrow dykes of aplite and andesite striking east and west. Black basalt and white andesite tuffs occur on the hills near Wallace mountain, to the east of the granodiorite. The rock in the immediate neighbourhood of the ores varies from quartz diorite to granodiorite according to the proportion of plagioclase feldspar present.

The ores consist of galena with argentite, sphalerite, ruby silver and tetrahedrite. These are associated with quartz, pyrite and, in rare cases, arsenopyrite. Native silver occurs near, and in, certain fault planes, and oxidized ores—silver chlorides—are sometimes encountered near the surface.

The veins vary in width from thin stringer to perhaps 10 ft. They strike east and west and dip to the south at an angle varying from 45° to almost 90°. A dip to the north has been noted, but may in this case be due to local displacement.

The vein matter consists of a very much silicified and altered granodiorite, accompanied by one or more bands of quartz. There is generally a sharp break between the composite vein material and the fresh granodiorite forming a well-defined foot and hanging wall. The relative proportion of quartz and altered granodiorite varies greatly; the stringers of quartz are more generally found near the walls.

The heavy stringers of quartz and occasional regular banding of the sulphides indicate that part of the vein was formed by fissure filling. The granodiorite within the vein shows evidence of crushing. Quartz fills the spaces between the fragments and quartz, and the sulphides can be seen replacing the original minerals of the granodiorite. Replacement of the country rock in the walls is not very evident and the ore sulphides appear to be absent. If replacement has taken place it has probably not extended more than a few inches from the lode.

In one of the Sally mines the ore was found to occur both in and alongside a dyke of fine-grained grey material. A dyke of andesite of the same texture and appearance occurs farther west. The dykes strike east and west like the ore fissures. Whether they bear any relation to the genesis of the ores can only be determined by further study.

The veins are cut by a series of fault planes having a north and south strike and a dip to the west of from 35° to nearly 90°. Instances of a northeast-southwest strike are said to occur. The displacement, which varies from a foot to over 300 ft., is toward the south when following the lead from west to east. There are one or two exceptions to this rule, but the displacement in such-cases is never very great. There are at least two series of north and south faults. In the Rob Roy No. 7 tunnel of the Sally Group a fault plane with a dip of 80° cuts one dipping 35°. There seems to be an upward movement on the western side of the steeper fault with a displacement of more than 300 ft.

Along the fault planes between the broken ends of the vein there is usually a thin band of gouge, kaolinized vein material and partly decomposed ore. Thin plates of native silver and calcite are usually found in or near these fault planes.

There is but little evidence of the oxidation of the vein material by surface waters. In some of the Sally mines oxidized ore has been found to a depth of 75 ft.; but in general the fresh sulphides are encountered quite close to the surface. The leached vein matter or gossan has doubtlessly been removed by glacial scouring.

On account of the limited extent of underground development, it is not possible to determine variations in the character or values of the ore relative to their depth from the surface. Values vary greatly in a lateral direction. Bunches of ore have been taken out which after sorting by hand averaged $200 to the ton; then again the lead will be almost barren. The occurrence of pay ore along a lead is, however, fairly constant. As an instance, the Sally mines, with 2,000 ft. of tunnelling, have shipped nearly 700 tons of ore averaging more than $100 to the ton, and have about 3,000 tons on the dump averaging perhaps $25 per ton.

The boundaries of the silver-bearing deposits have not been definitely determined. Properties of the "shipping class" lie within an area of perhaps two square miles on the western and southern slopes of Wallace mountain. The Sally mines are three miles by wagon road from Beaverdell and 1,500 ft. above the town, while the properties on the far side of Dry Creek would be about one and a-half miles farther east.

On the western slope of the mountain the ore has been worked by tunnels driven along the veins, while in other parts of the area, shafts have been sunk from 40 to 100 feet deep and the ore taken out by drifting and stoping.

The ore shipped from three of the properties would total 925 tons valued at about $98,500. Of this the Sally Group produced $73,000, the Bounty Fraction and Duncan close to $16,000 and the Rambler a little over $9,500. These returns were given me by the managers or owners of the mines. Ore has also been shipped from the Bell claim.

A serious drawback to the development of the camp is the excessive cost of transportation. The cost of freight and treatment on ore consigned to the Trail works is from $30 to $35 per ton; while the carriage charges to Midway alone are $16 per ton. On this account, ore averaging less than $100 per ton cannot be mined at any great profit. Railway connections to Beaverdell and the establishment of concentrating works to eliminate the slow and expensive hand-sorting of the ore, would do a great deal towards the opening of the silver deposits.

The Carmi mine, a gold and silver-bearing deposit, is situate southwest of the now abandoned town of Carmi, five miles above Beaverdell. The mine has been abandoned for some time and the shaft is filled with water. The following notes were made after an investigation of the ore dump and surface outcrops:—

The ores consist of zinc blende, chalcopyrite, pyrite (probably gold-bearing) and galena in a gangue of quartz and ferruginous dolomite. A small amount of molybdenite is also present.

They occur in a vein from 2 to 4 ft. wide, which dips to the south an angle of 45°. The country rock is a gneissic granodiorite of the same character as that on Wallace mountain. The vein occurs along a dike of dense fine-grained aplite or andesite. The proportion of quartz and dyke matter between the granodiorite walls varies in a very marked degree. The ore is found in both the dyke and the quartz.

A shaft 183 ft. deep has been sunk on the western end of the property and 200 ft. of drifting therefrom. There is also a tunnel 86 ft. long and another shaft 40 ft. deep. A mill with a 10-stamp battery was erected in 1904, and 400 tons of waste treated with amalgam plates and by the cyanide process. Between 1899 and 1900, nearly 900 tons averaging $26 per ton in gold and silver were shipped to the smelting works at Greenwood.

Promising showings of silver and copper have been opened in other parts of the West Fork valley. Some of these will doubtless be developed when the facilities for handling ore shall have been improved.

THE STANDARD MINE, SILVERTON, B.C.

By JOHN VALLANCE.

(Western Branch Meeting, Trail, B.C., May. 1911).

The Standard group, includes 13 mineral claims, situated at an altitude of 3,354 feet, on the south slope of Silver Mountain, about one and a half miles easterly from Silverton, a mining town on the east shore of Slocan Lake.

The original claims of the Standard group were located in the year 1892. The locators, after doing enough work to secure Crown grants, allowed the property to lie unworked for more than ten years. During the year 1904 the group was bonded by J. A. Finch and G. H. Aylard, who at once proceeded to carry out a plan to thoroughly develop the property—a plan fully justified by results. Since 1906 mining and development work have been steadily continued. During 1909–10 the 'big ore shoot' was cut by the lower levels and the present remarkable showings of ore exposed.

The enclosing country consists of old and very silicious sedimentary rocks cut in places by masses and dykes of an eruptive rock generally classed as granodiorite. A large "boss" of this rock occurs along the east side of the Standard claim, and is apparently the centre from which local dykes radiate. The sedimentary strata is mainly hard blocky argillites, silicious shales, and impure quartzites.

Vein and Ore Bodies.—The Standard vein is a strong fissure cutting the bedding planes of the enclosing sedimentary rocks; a dyke of quartz-diorite-porphyry is intruded into the fissure and lies along the footwall side.

This dyke rock is much altered and appears to be, in some manner, closely connected with the principal ore-bodies found in the vein. Probably the clayey-talcose matter of the altered dyke has influenced the course of the mineral-bearing solutions and caused the ore to be deposited on or near the dyke where it is most frequently found.

There is much evidence of large and repeated movements in the vein, especially towards the hanging-wall side and at some points movements have occurred after the formation of the ore-bodies, masses of galena occurring deeply striated by movement of adjoining hard gangue material.

The strike of the vein is n. 49°. e. (mag.) and the dip, which is variable, changes from 40° in the upper levels to 58° on No. 5 level.

The principal minerals are argentiferous galena and zinc-blende, with some pyrite, chalcopyrite and grey copper (freibergite) as associated minerals. The Freibergite usually occurs as specks and bunches mixed with the galena, but occasionally with the blende, and it is evidently highly argentiferous, as specimens have assayed up to 2,000 silver per ton.

The vein gangue is of quartz, limespar and spathic iron with enclosed fragments of shale and occasional masses of altered dyke rock.

In the workings, above the fourth level, the ore bodies are lenticular and follow a zone having a pitch of about 30°. From No. 4 to No. 5 level the big shoot of galena has a pitch of near 28°.

The big shoot, where cut by No. 5 level, occurs where the vein gradually widens from four to thirty feet. Here the clean shipping ore has its maximum width of 15 feet; the rest of the vein, 15 feet, being high-grade milling ore with included masses of clean galena. From this point to the present face of No. 5 level, the vein continues to widen and the ore body to gradually change in character, the shoot of clean ore changing to a great mass of milling ore enclosing irregular bodies of solid galena.

Workings.—The mine workings consist of six levels, with connecting raises, from No. 5 upward, and a number of crosscuts, on the levels, where the vein is wide. Not including stopes and cross-cuts, the mine openings aggregate a length of 8,500 feet. The depth, on the vein, from No. 1 to No. 6 level is 740 feet.

After connection shall be made by raise with No. 5, No. 6 level will become the main adit for the mine, the new tramway connecting this level directly with the mill at Silverton.

Ore from stopes above No. 4 level was mined by the usual overhand method, the ground being timbered with a two-piece set, or by stulls, as required. In the lower levels, where the vein is wider, the large ore body will be extracted by overhand stoping, while the 'square set' system of timbering will be followed.

The ore as mined is roughly graded in the workings, the cleaner ore going to the ore-houses for sorting, the cobbings from this and all the second grade material being placed on the milling dumps.

Ore Shipments.—Shipments to the smelter, to date, represent 4,418 tons. The average contents were:—silver 78.46 oz. per ton; lead 62.5 per cent., and zinc 5.88 per cent. Some shipments gave returns of over 100 oz. silver, and others as high as 73 per cent. lead per ton.

In addition to the large bodies of ore in the mine, a large tonnage of ore, sorted and ready for shipment, is in the ore-houses, and the several milling dumps are estimated to contain over 8,000 tons of ore which will concentrate 3½ or 4 tons to one of shipping product.

Equipment.—Preparatory to more active mining and development, the company is adding the following equipment:—A 10-drill Rand duplex compound compressor, a Riblet tramway, and a mill with a capacity of 100 tons a day.

The tramway will have a length of 7,900 feet, and a grade of 16 per cent.; its carrying capacity will be 20 tons an hour.

The mill will have a crushing capacity of 200 tons and a dressing capacity of 100 tons of ore a day. Water power will be used for both compressor and mill, the required water being taken from Four-mile Creek, which flows within 3,000 feet of the mine.

The compressor will be placed on Four-mile Creek, as near the mine as practicable, and the water for power, at this point, will have a head of 160 feet. The total length of flume, from intake to mill, will be about two and a half miles and the head of water will here be 275 feet.

Without mishap or delay, the tramway and compressor should be in use by July, 1911, and the mill ready for service by October.

It may be stated in conclusion that the present satisfactory condition of the property in respect of the large available ore supply is directly attributable to the well-planned and well-ordered system of mine-development, which has been consistently carried forward, by the present operators.

THE IRON ORE RESOURCES OF THE WORLD.

By FRANK D. ADAMS, Montreal, Que.

(Annual Meeting Quebec, 1911).

At the meeting of the Eleventh International Geological Congress, held in Stockholm, Sweden, in August, 1910, the results of a very interesting and valuable investigation into the Iron Ore Resources of the World, undertaken by the officers of the Congress, were presented to the members.

The results of this investigation are published in two large quarto volumes, comprising approximately 1,100 pages, with 137 illustrations and 28 plates of sections, photographs, &c., the report being accompanied by a large atlas of maps showing in detail the distribution and character of the iron ore deposits in the more important iron fields of the world. In preparing this great report the co-operation of the Geological Surveys of the various countries was enlisted, while in the case of countries having no Surveys the assistance of gentlemen having especial knowledge of the iron ore deposits and resources of such countries was obtained. Seventy-five countries, including all those that are known to contain deposits worthy of mention, have thus been made the subject of investigation, and the report contains as accurate a statement as it is possible to make concerning the reserves of iron ore which are found within their borders.

It is proposed in the present paper to give to the members of the Canadian Mining Institute a summary of the results obtained in this investigation, since the question of the iron ore

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The Iron Ore Resources of the World.—An Inquiry made upon the initiative of the Executive Committee of the XI International Geological Congress, Stockholm, 1910. Publisher, Generalstabens Litografiska Anstalt Stockholm. (2 vols. and atlas), price £3.

resources of the world and their distribution is a matter of the greatest importance at the present time.

It is evident that in making such an estimate it was possible to obtain much more accurate data for some countries and districts than for others, and in asking for statistics from the various surveys, etc., the Swedish committee accordingly requested that the returns sent to them should show the iron ore resources classified as follows:—

(*a*). Including those cases in which a reliable calculation concerning the extent of the deposit, based on actual observation and exploration had been made;

(*b*). Including those deposits in which only a very approximate estimate of quantities could be reached;

(*c*). Embracing those deposits about which too little was known to enable any estimate in figures to be returned, although the reserves could be determined in a general way as "enormous," "large," "considerable" or "small."

It therefore becomes necessary in correlating the results of the investigation, to set down separately the "actual reserves," or those whose extent is known and which are immediately available, and the "potential reserves," whose actual extent must be less certain but which, nevertheless, can be estimated, although under present conditions they are not as a general rule immediately susceptible of utilisation. These, however, may be drawn upon in the future.

The total amount of the iron ore resources of the world known and recorded in the reports is set forth in the table below. The letters "M.T." stand for "million tons."

SUMMARY OF WORLD'S IRON ORE RESERVES.

	Actual Ore M.T.	Reserves Iron M.T.	Potential Ore M.T.	Reserves Iron M.T.
Europe.	12,032	4,733	41,029	12,085 + considerable
America.	9,855	5,154	81,822	40,731 + enormous
Australia.	136	74	69	37 + considerable
Asia.	260	156	457	283 + enormous
Africa.	125	75	many thousands	many thousands + enormous
Totals.	22,408	10,192>	123,577>	53,136 + enormous

The world's actual readily available iron reserves thus amount in round figures to about 10,000 million tons.

To what extent the future production of iron will become dependent upon low-grade ores is still more apparent from the following table, which shows the comparatively small existing reserves of ores which contain more than 60% of iron.

THE CHIEF IRON ORE DEPOSITS NOW KNOWN WHICH CONTAIN 60% OF IRON OR UPWARDS.
(The potential reserves are in brackets).

	Supplies of Iron Ore M.T.	Mean Percentage of Iron	Metallic Iron in the Iron Ore M.T.	Remarks
EUROPE—				
Russia: Krivoj Rog	86	—	53.5	
Caucasus	13	60	6.8	
Sweden: Northern Sweden	1,035 (123)	60–70	673 (80)	
Central & Southern Sweden	about 60	60	36	
AMERICA—				
Newfoundland				Enormous amounts of titaniferous magnetite with 65% Fe.
Mexico	about 55	60–70	about 30	
West Indies	3	about 60	1.8	
AUSTRALIA—				
West Australia	26	63–68	about 15	
South Australia	(21)		12	Fe + Mn >60%
Queensland	(13)		7	Fe + Mn >60%
Tasmania	23	about 64	15	
ASIA—				
Persia	(30)	60	(18)	
Br. India	(400)	64–68	(250)	
China	(100)	60–62	(60)	
Totals	about 1,300 (687)		850 (about 408)	

From this table it is seen that about four-fifths of the reserves of the very high-grade iron ores which are now known, are contained in the deposits of Northern Sweden. These ores, therefore, will undoubtedly play a very important part in the future development of the iron industry.

The following synoptical table, compiled by F. R. Tegengren, shows the iron ore resources of the various countries of the world and is taken from the report.

EUROPE.

Country & District	Variety of Ore	Actual Ore Supplies M. T.	Equivalent Metallic Iron M. T.	Potential ore Supplies M. T.	Equivalent Metallic Iron M. T.
FRANCE—					
Lorraine	Oolitic ores	3,000	1,000	.....	.....
Western France (major deposits)	(Hematite & Spathic ore	200?	90	.....	.....
Pyrenees & minor deposits	do	100?	50	.....	.....
Totals	.....	3,300	1,140	.....	
LUXEMBURG	Oolitic ore	270	90	.....	
SPAIN—					
Biscay (Bilbao)	Red hematite	61	32	.....	.....
Lugo	(Magnetite and Brown hematite)	122	56	.....	
Oviedo	?	111	50?	Considerable	Considerable
Leon	Spathic ore, etc.	166	78	.....	
Teruel and Guadalajara	Brown hematite	133	74	Considerable	Considerable
Other districts	.....	118	59	.....	
Totals	.....	711	349	Considerable	Considerable
PORTUGAL—					
Tras-os-montes	?	.....	.....	45	22
Central Alemtejo	Limonite, Magnetite	.....	.....	17	9
Western	Magnetite, Limonite	.....	.....	10	6
Porto de Moz	Red hematite	.....	.....	3	2
Totals	.....	.....	.....	75	39

ITALY—					
Elba	Specular & Red hematite, Magnetite, Limonite	6	3.3	...	...
Aosta Valley—					
Liconi	Magnetite	...	...	0.5–1	0.8–1 (Liconi, Traversella, Val d'Aspra)
Traversella	do	...	...	0.8–1	
Val d'Aspra (Tuscany)	Limonite	...	...	0.5	
Totals	...	6	3.3	about 2	about 1
SWITZERLAND—					
Basin of Delsberg	Bone ore	1	0.4	...	...
Gonzen	Hematite	0.6	0.4	...	...
Erzegg-Planplatten and others	Chamoisite, etc.	...	...	2	0.8
Totals	...	1.6	0.8	2	0.8
AUSTRIA—					
Bohemia	Chamoisite	35.1	14	291.5	85
Styria (ore with >25%Fe)	Spathic Ore	206	72	21.9	7.6
Carinthia	Limonite, Spathic Ore	7.2	3.1	7.3	7.6
Moravia and Silesia	...	2.6	1.3	2.5	1.1
Totals	...	250.9	90.4	323.2	97
HUNGARY—					
Szepes-Gomorer (Carpathian m.)	Spathic ore Limonite	26.1	10	47.7	18.7
Hunyad	Princ. Spathic Ore	3.7	1.5	13.3	5.3
Banat	Magnetite, Hematite, Limonite	1.8	1.	5.3	2.9
Croatia and other districts	...	1.5	0.6	12.6	7.2
Totals	...	33.1	13.1	78.9	34.1

EUROPE.—*Continued.*

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
BOSNIA AND HERZEGOVINA—	Hematite, Spathic Ore	......	......	21.9	11.3
SERVIA	Magnetite, Hematite, Limonite	......	......	Probably moderate.	Probably moderate
BULGARIA	Magnetite, Hematite, Slag	......	......	1.4	0.7
GREECE	Princ. Chromif, Magnetite	100	45	Probably moderate.	Probably moderate
TURKEY	......	......	......	Considerable	Considerable
RUSSIA—					
Ural	Magn., red and brown, Hem., Carb.	281.9	135.3	Very Considerable	Very Considerable
Central Russia	Brown Hem., Carb.	......	......	789	315
Poland	Brown Hem., Carb.	33.7	10.8	266.3	109.2
Southern Russia	Red and br. hem., Carb.	536.0	233.3	Considerable	Considerable
Caucasus	Magnetite	13.0	7.8	1	0.5
Totals	......	864.6	387.2	>1056.3	>424.7
FINLAND—					
Jussaro	Magnetite	......	......	30–35	11–13
Pitkaranta & Kelivaara	do	......	......	13.5	4
Totals	......	......	......	about 45	about 16

Sweden—					
Northern Sweden	Princ. Magnetite	1,035	670	123	80
Central & South Sweden	do	123	70	55	25
Totals		1,158	740	178	105
Norway—					
Syd Varanger, Dunderland Salangen and others, (concentrating ores)	Magnetite and Hematite.	350	115	1,500	500
Lump ores	Magnetite.	17	9	30	16
Other deposits	Titanifer-Magnetite	...	...	15	9
Totals		367	124	1,545	525
Great Britain—					
Cleveland	Ironstone	500	150	2,500	750
Northamptonshire	do	200?	70	800	280
Lincolnshire and others	do	100	35	900	300
Scotland, South Wales and other districts	Clay-ironstone			33,500	9,500
All other ores	Red and brown hematite	500?	200	...	
Totals		1,300	455	37,700	10,830
Holland	Limonite, Bog Ore	Insignificant	Insignificant	Moderate	Moderate
Belgium—					
Namur and Liege	Sedimentary Hematite	50	20	...	...
Central and S. Belgium	Fissure veins, Gossan Limonite	4.5	2	...	...
Antwerp and Limburg	Surface recent Limonite	7.5	3	...	...
Totals		62	25	...	...

EUROPE.—*Continued.*

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
GERMANY—					
Lorraine.	Oolitic ore.	2,330	755	Very Considerable	. . . . . .
Lahn and Dill district.	Red and brown Oematites	258.3	124	Considerable	. . . . . .
Ilsede and Salzgitter.	Brown Hematite.	278	100	Very considerable	. . . . . .
Bavaria.	Limonites, Oolitic ore.	181	62	Considerable	. . . . . .
Siegerland.	Spathic Ore (manganiferous).	115.7	53		Moderate
Thuringian Forest.	Chamoisite.	104.2	46		Considerable
Wirtemberg.	Limonite, Bone Ore.	110	42		Very considerable
Other districts.	. . . . . .	230.5	88		Considerable
Totals.	. . . . . .	3,607.7	1,270	Enormous	Enormous
Totals for Europe.	. . . . . .	12,031.9	4,732.8	41,028.7+ Enormous	12,084.6+ Enormous

AMERICA.

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
CANADA —	Magnetite, Hematite, Siderite, Jasper, Clay-ironstone.	Considerable		Probably enormous	
NEWFOUNDLAND—					
Bell Island.	Red Hematite.	3,635	1,961	. . . . . .	. . . . . .
Western part.	Titanif. Magnetite.	. . . . . .	. . . . . .	Enormous	Enormous
Other deposits.	Sand, Clay-ironstone.	. . . . . .	. . . . . .	Some hundred	Some hundred
Totals.	. . . . . .	3,635	1,961	Enormous	Enormous

AMERICA.—*Continued.*

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
UNITED STATES OF AMERICA: *The Eastern region.*					
Clinton	Red Hematite	505.3	187	1,368	481
Ohio and other States	Carbonate Ore	....	....	308	90
Other deposits	Red and brown Hematites, Magnetite	204.5	95.4	265.5	119
Lake Superior region	Specular Hematite, Red & brown Hematites, etc.	3,500	2,000	72,000	36,000
Mississippi valley	Brown, red & specular Hematites	45	21	830	382
Cordilleran region	Magnetite & Hematite	3	1.2	115.8	50
Adirondack, etc.	Titaniferous Magnetite	....	....	218	100
Totals	....	4,257.8	2,304.6	75,105.3	37,222
MEXICO—	Magnetite	55	30	Probably	considerable
CENTRAL AMERICA—	Magnetite	....	....	Exist	Exist
WEST INDIES—					
Cuba	Specular iron & Magnetite	3	1.8	7	4
Cuba	Brown Hematite	1,900	855	1,000	450
Totals	....	1,903	856.8	1,007	454
COLOMBIA, VENEZUELA, BOLIVIA AND CHILE	Magnetite & Hematite	4.2	2	Considerable	Considerable

AMERICA.—*Continued.*

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
BRITISH GUIANA	Limonite, Ironstone, Ti-tanif. iron sand	...	...	Exist	Exist
DUTCH COLONIES	Hematite, Limonite, Ti-tanif. iron sand	...	...	Exist	Exist
BRAZIL— Minas Geraes	Itabirite ores (Hematite).				
	Carry	...	...	2,000	1,200
	Rubble	...	...	2,000	1,000
	Canga	...	...	1,710	855
Totals	...	...	...	>5,710	>3,055
ARGENTINE	Magnetite & Hematite	...	...	Exist	Exist
*Totals for America:—**	...	9,855	5,154.4	81,822.3+ Enormous	40,731.4+ Enormous

AUSTRALIA

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
WESTERN AUSTRALIA—					
Wilgi Mia (Weld Range), Murchison gold field	Hematite with Magnetite	...	...	26	15
Other deposits	Hematite, Laterite, Bog Ore	...	...	Considerable	Considerable
Totals	...	...	...	26+Considerable	15+Considerable

SOUTH AUSTRALIA—					
Iron Monarch & Iron Knob	Hematite	.....	.....	21	12
Peralilla	Limonite, Clay-ironstone	.....	.....	0.1	0.05
Donelly's	Limonite	.....	.....	0.5	0.25
Totals	.....	.....	.....	21.6	12.3
QUEENSLAND—					
Mount Leviathan	Hematite	.....	.....	10.5	5.2
Mount Pisa	do	.....	.....	1.0	0.5
Iron Island	Magnetite and Hematite	.....	.....	2.2	1.3
Totals	.....	.....	.....	13.7	7
NEW SOUTH WALES—					
Cadia	Princ. Hem., Magn., Carb	39.6	21.8	.....	.....
Carcoar	Hematite & brown ore. ...	3.2	1.7	.....	.....
Other deposits	Princ. Br. Hem. & Magn.	6.1	3.3	.....	.....
Williams & Karuah River	Titanif. Magn	.....	.....	2.1	0.94
Wingello	Pisolitic Aluminous Ore	.....	.....	3	0.76
Totals	.....	48.9	26.8	5.1	1.7
VICTORIA—	Ironstone, earthy Hematite	.....	.....	Moderate	Moderate
TASMANIA—					
Blyth River	Hematite	23	15	.....	
Mt. Vulcan, Barnes Hill	Brown and red Hematites with Magn	.....	.....	2	1
Totals	.....	23	15	2	1
NEW ZEALAND—					
Parapara	Chiefly Limonite	64	32	.....	
New Plymouth	Titanif. Magnetite	.....	.....	Considerable	Considerable
Other deposits	Limonite	.....	.....	0.2	0.1
Totals for Australia	.....	135.9	73.8	68.6+ Considerable	37.1+ Considerable

ASIA.

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
ASIATIC RUSSIA—					
Kirghiz steppes	Magnetite	...	...	7	4.2
East Siberia	Magnetite	...	...	14	7.6
Far East	Magnetite & Brown Hem.	...	...	6	3
Totals	...	...	...	27 + Considerable	14.8 + Considerable
PERSIA—	Specular Iron & Magn.	...	...	30 + Considerable	18 + Considerable
BRITISH INDIA—	Hematite	100	65	400 + Considerable	250 + Considerable
CHINA—	Hematite	100	60	Probably Enormous	Probably Enormous
JAPAN—	Magn., Hem., & Limonite	55.6	28	Moderate	Moderate
COREA—	Magnetite Hem. and Limonite	4.0	2	Probably Moderate	Probably Moderate
PHILIPPINES—	Hem. and Magnetite	0.8	0.5	Exist	Exist
BRITISH DOMINIONS—	Limonite, Laterite deposits and Magn.	...	...	Considerable	Considerable
DUTCH COLONIES—	Titanif. Magnetite sand	...	...	Considerable	Considerable
Total for Asia:	...	260.4	155.5	457 + enormous	282.8 + enormous

AFRICA

Country & District	Variety of Ore	Actual Ore Supplies M.T.	Equivalent Metallic Iron M.T.	Potential ore Supplies M.T.	Equivalent Metallic Iron M.T.
ALGERIA AND TUNIS—	Hematite.	about 125.	about 75.	.....	.....
EGYPT—	Hematite, Limonite, Iron stone, Magnetite.	.....	.....	Moderate	Moderate
ANGLO-EGYPTIAN SUDAN—	Lateritic Ores.	.....	.....	Many thousands	Many thousands
BRITISH DOMINIONS—	Magnetite, Hematite, Limonite, Laterite, etc.	.....	.....	Considerable	Considerable
CONGO—	Magnetite, Hem., Limon.	.....	.....	Considerable	Considerable
GERMAN COLONIES—	Red & br. Hem., Magn., (partly titanif.).	.....	.....	Considerable	Considerable
RHODESIA—	Laterite, Hem., Magn.	.....	.....	Many thousands	Many thousands
TRANSVAAL—	Magnetite (partly titanif) and Hematite.	.....	.....	Enormous	Enormous
CAPE COLONY—	Magnetite.	.....	.....	Considerable	Considerable
Total for Africa	.....	125	75	Enormous	Enormous

If we survey the continents in succession we find that in Europe the greatest actual ore reserves are the minette ores distributed between Germany, France, Luxemburg and Belgium, amounting together to about 1,850 M.T. metallic iron. Next in order come the ore reserves in the North of Sweden with about 673 M.T. Among the potential reserves by far the largest are the clay-ironstones of Great Britain, chiefly divided between two centres, viz., one in England and Wales with 7,100 M.T., the other in Scotland with 2,400 M.T., are first.

In North America by far the most important ore reserves are found in the Lake Superior region, representing about 2,000 M.T. actual and 36,000 M.T. potential reserves expressed as metallic iron. Next to these are the considerable deposits in Newfoundland with about 1,960 M.T. actual reserves. In Cuba there are about 857 M.T. actual and 454 M.T. potential reserves.

In South America only one single important iron ore district is now known. This is situated in Brazil in the province of Minas Geraes and contains at least 3,055 M.T. potential iron reserves.

In Africa we can scarcely speak of any definite iron ore centres; although as such may possibly be classed the enormously large bodies of titaniferous magnetite in the Bushveld in the Transvaal, whose content cannot as yet be expressed in definite figures. The other large developments of iron ore in the African continent belong to two very wide-spread geological formations, the Pre-Cambrian formation with its banded ironstone which is met with in Cape Colony, the Transvaal and Rhodesia, and the Laterite formations in tropical Africa, the Congo, the Anglo-Egyptian Sudan, etc.

In Asia and Australia no iron ore centres of any great importance are known.

But nevertheless we must not ascribe too much importance to the geographical situation of the iron ore centres. The question as to where an iron industry is to develop itself will in each case be one depending upon a great many factors, among which the presence of iron ore is only one. Other very important factors are the supplies of fuel, cost of assembling the raw materials and the facilities for disposing of the product, etc. The last mentioned factor tends to build up iron industries within or close to the districts of consumption.

If, leaving the consideration of the ore resources by continents, we proceed to glance at the reserves of the various countries, we shall find that, in Europe, Germany and France have the greatest actual iron reserves, viz., about 1,270 and 1,140 M.T. respectively, expressed as metallic iron. Furthermore, Sweden possesses 740 M.T. actual and 105 M.T. potential reserves and Russia about the same quantity. Next in order comes England, whose ore reserves must, however, to a considerable extent be classified as potential rather than actual.

The report shows England's peculiar position with regard to the raw material for her iron industry. Although she possesses within her borders sufficient ore reserves to support that industry for an unlimited time to come, she imports large quantities of iron ore from foreign countries. England's import of iron ore amounted in the course of the year 1907 to 7.6 M.T., which, with an average of 50% Fe, this, taken at a low figure, represents 3.8 M. T. of pig iron. As the entire pig iron production of England during the same year reached 10.1 M.T. it is seen that about 37% of the production of pig iron is derived from the ores of foreign countries.

The cause of this is to be found in the fact that most of England's iron ores are so low-grade, that it is more advantageous under present economical conditions to smelt foreign ores in England. England's greatest ore reserves, which undoubtedly will be made use of at some future time, are of such a nature as to make it impossible for them to compete at present with the foreign ores.

In Africa, Rhodesia with its enormous quantities of banded ironstone and laterite ores, the Transvaal with its banded ironstone and titaniferous magnetites, Cape Colony with banded ironstone, and the Anglo-Egyptian Sudan with laterite ores, probably lead.

In Asia and Australia, no countries seem so far to signalise themselves by any very large iron ore reserves.

In America we have, in the first instance, the United States with about 2,300 M.T. actual and the enormous figure of 37,000 M.T. potential reserves, expressed as metallic iron.

The section of the Report dealing with Canada, is, it must be confessed, rather disappointing. The Canadian occurrences are treated by provinces and the chief deposits of iron ore in each are noted and briefly described. Although in a number of cases the length and breadth of the ore body, as well as its depth as shown by borings, are given, in no case is any attempt made to calculate, even in a most general way, the ore reserves which are thus indicated.

The actual reserves of iron ore in Canada are merely stated to be "considerable," while the potential reserves are set down as "probably enormous."

Newfoundland occupies, on account of the ore reserves brought to light within the last few years, a prominent position with about 1,960 M.T. of actual resources, expressed as metallic iron.

An excellent description is given by J. P. Howley of the Belle Island deposits in Newfoundland, which he estimates to contain 3,635 million tons of ore. He also draws attention to the fact that there are in the western portion of the island enormous deposits of titaniferous magnetite, running as high as 65% in iron, free from sulphur and phosphorus but containing from 4 to 15 per cent of titanic acid. No attempt has hitherto been made to utilize these ores.

The resources in the West Indian Islands (properly speaking of Cuba) estimated at 857 M.T. of iron actual, and 454 M.T. potential resources, are in themselves considerable, and will, on account of their favourable situation, no doubt play an important role in future.

A very important question now presents itself:—*How long will it be before the iron ore resources of the world are exhausted?*

As has been shown above, the world's readily available iron ore resources amount, in round numbers, to 10,000 million tons if expressed as metallic iron.

As the production of pig iron at present can be put down at about 60 M.T. yearly, this supply would not be sufficient for more than about 170 years, on the supposition that the production of pig iron remained constant.

This production, however, as a matter of fact, has been rising rapidly during the 19th and 20th centuries, as shown by the accompanying table:—

Production of Pig Iron in the year	1800	0.8 M.T.
" " " "	1850	4.8 "
" " " "	1871	12.9 "
" " " "	1891	26.2 "
" " " "	1909—about	60. "

As will be seen, speaking generally, the production of pig iron has risen in a geometrical ratio, so that it has more than doubled every twenty years. If we suppose that the consumption of iron in the future will continue to rise at the same rate, the actual iron ore reserves would be sufficient to supply the requirements of iron of the world for about 60 years only.

As Professor Kemp has observed, however, we cannot anticipate the continuance of the geometrical ratio of increase for the production of iron ore. We are more likely eventually to attain a fairly stable annual output. What this will be, however, it is impossible to state. With the exhaustion of the richer ores the poorer "potential reserves" will be drawn upon and with their introduction into the field a general decline in the percentage of iron in the iron ores which are mined will probably take place. This decline will, at first, be most marked in those countries where the richest ore has naturally been the first to be utilized, but the percentages as they become lower will soon become fairly stable in America, as they have already done in Germany. When a 30% ore comes into general use the iron ore reserves will be such that their exhaustion may be said to be indefinitely postponed. As will be seen by the table given above, the potential ore reserves of the world are estimated to amount to 53,136 M.T., expressed as metallic iron, plus an enormous and at present unknown additional amount.

It would seem that the Aluminium-Reïnforced Concrete Age—about which we have recently heard, must still be in the distant future.

With the approaching exhaustion of the richer ore bodies, howevever, our thoughts naturally turn to *Conservation*—not to the cessation of work on deposits which are now required by man—but to the husbanding of our resources of high-grade ore through the reduction of waste and the abandonment of wasteful processes.

The consideration of this phase of the question has led to action on the part of the governments of certain countries. The following extract from an address made by His Excellency A. Lindman, Prime Minister of Sweden, in opening the discussion on the Iron Ore Resources of the World, which took place in the Hall of the Nobles in Stockholm, on the occasion of the meeting of the

11th International Geological Congress, sets forth certain recent action taken by the Swedish government.

"Very likely you all know that our largest iron ore resources (those of Sweden) are in Gellivare and Kiirunavaara. When the government decided in 1898 to build a railway for the exploitation of the last mentioned mining field, the idea had already been conceived that a limitation of the export was desirable, and this limit was put down at 1,200,000 tons a year. In the same degree as it became more and more obvious that these ore resources were enormous and could easily be disposed of, the demand for an increased export grew, but at the same time also the claim of the state to regulate the exportation in such a manner that it should not go on too rapidly. This led to negotiations between the government and the owners of the ore fields, with the results that an agreement was entered into in 1907. According to this agreement the state became the owner of half the shares in the company that now owns the mines in Gellivare and Kiirunavaara, and also became sole owner of certain other mining fields (Mertainen, Ekstromsberg and others), and in return for this undertook to carry 75 million tons of ore from Kiirunavaara and 19 million tons from Gellivare at a certain freight during a period of 25 years, besides which certain other regulations for the benefit of the company were made. These quantities have by a later agreement, in connection with the acquisition of Svappavaara ore field by the state, been somewhat increased. It was considered also to involve certain benefits for the state to become a shareholder in a limited company, but on entering into the contract it was also decided that the state at the end of 25 years shall be entitled on certain conditions to take over the entire stock of shares. The agreement may with every reason be said to have been advantageous for both parties, and forms a good example of co-operation between the state and the individual.

"This contract has quite naturally been discussed by customers of the ore, but anyone of you, gentlemen, would certainly have had the same patriotic feeling for his country and would in like case have understood the justifications and desirability of the state obtaining the determinative right concerning this enormous natural wealth upon crown land, which, on account of the exceptionally high grade ore, will always possess a high value.

"The government has also in other ways than by limitation of the export contributed towards a rational exploitation of our iron ore resources. Parliament has thus passed an act this year for the construction of an electric power station at the Porjus Fall, in the Great Lule River, about 50 km. to the south of Gellivare, for the electrification, in the first instance, of the railway between Kiruna and Riksgränsen, upon which railway—situated far north of the Arctic circle—by means of electric locomotives hauling trains of a weight of 2,000 tons loaded with iron ore will be run. There is also a large surplus of power that may be of enormous importance to the treatment of iron in case the attempts succeed that have been made to smelt iron by electricity at the large governmental power-station at Trollhättan. These attempts have been made with the co-operation of the government through the agency of the Järnkontoret, our institute for the advancement of iron industry.

"These, gentlemen, are some of the measures that have of late years been taken for the retention of a suitable use of our iron ore resources, and I trust that this information will be of some interest to you.

"I will, furthermore, only add that I consider the governments could, and in many respects ought to, further a rational use of the natural resources. This can be done by liberally assisting such scientific work as leads to a more intimate knowledge of the same, by arranging systematical, geological and technical researches, by assisting in elevating the respect for all practical work done with scientific method, and last but by no means least, by giving such instruction in our schools that the young men and women on leaving school understand the value and importance of an economical management of the natural wealth

"The co-operation of the company and the state in this case has proved most beneficial to both, the company obtaining, among other things, cheap and excellent transportation for their ore, through a desert country far within the Arctic circle, which is one of the important factors which enable the company to pay large dividends upon its stock, while the government also secures a regular income and still maintains a certain beneficent control of one of the great national assets, so as to ensure its continued development in the best interests of the state through centuries to come."

In an interesting contribution to this same discussion, Professor E. De Launay, pointed out that in connection with the consideration of the iron ore reserves of the world it is necessary to remember that there are certain factors which will influence the development of the iron trade as time goes on, and may even cause certain centres, which now are of great importance in the iron trade, to lose ground and to be replaced by others which are now of very subordinate importance.

The first of these factors is the probable discovery of new methods of working and of treating ores, among which may be mentioned the development of electric smelting.

The second factor consists in the opening up of new means of communication or the perfecting of methods of communication now imperfect, and consequently expensive. Developments along this line would lead to the opening up and making available of great deposits which at the present time it is impossible to utilise.

The third factor mentioned by De Launay is the influence on the iron trade of the shifting of population, and the growth in this way of new commercial centres of demand and consumption.

DISCUSSION.

DR. J. F. KEMP:—The question of the exhaustion of our iron ore resources is an exceedingly serious one. It is not to be assumed that the production of iron will continue to be maintained at the same great ratio of increase, which as indicated by Dr. Adams, has been a feature of recent developments. In America, for example, we have been skimming the cream of our product. With the utilization of lower grade ores, costs necessarily increase. Now and again, too, we have "off years." In the United States our average annual production is in the neighbourhood of fifty-three million tons; but in the panic year of 1908 the output declined to only thirty-five millions. Hard times thus reduce production and ease the drain on our resources. Normal activity, however, was soon thereafter resumed and the iron production of the United States is again fifty-three million tons, at which mark it has been fairly uniformily maintained for the past two or three years.

In reference to possible economies to be effected by the introduction of new methods in blast furnace practice, it should be borne in mind that about two-thirds of the coke charged in the furnace is employed in the generation of heat, which might be replaced by electrical energy, when the relative cost should render this possible, thereby reducing the consumption of coke to the one-third required for the chemical reduction of the ore. In the case of electrical smelting this one-third again might itself be replaced by some cheaper form of carbon, such as refuse charcoal or anthracite culm. Coke is, however, at present the all-important consideration. For the immediate future there seems to be no likely substitute, and as our iron furnaces get larger and larger, we demand a stouter and stouter coke and therefore, restrict the coal fields from which the proper fuel can be drawn. There are other factors which make us cautious in attributing a limited life to our iron resources. The scrap iron, for instance, accumulates and, to a large degree, is again returned to the furnaces. This supply lessens necessarily the drain upon the mines and will in some measure offset the excessive demands made upon them.

When we in America make calculations, we must also carefully consider the yield of the iron ores used here, as compared with those employed abroad. In America the general yield averages about 50 per cent.; but if we take the great deposits in Luxembourg, France and Germany, the ores afford between 30 and 40 per cent.

The cost, however, is in the long run the great point to be considered, for the price at which an article can be supplied will in a great degree determine its utilization.

One fact brought out in Dr. Adams' paper was the very emphatic delimitation of the iron industry to Europe and North America. When one considers the small portion of the total area of the world which these districts constitute one is impressed by the concentration of the iron industry. We can even focus our attention down to two or three countries in Europe, and we can restrict ourselves to the northeastern part of the United States and to eastern Canada as the centres of the industry for this the most useful of the metals.

THE UNDEVELOPED IRON RESOURCES OF CANADA.

By A. B. WILLMOTT, Toronto, Ont.

(Annual Meeting, Quebec, 1911).

We may now fairly assume that the iron and steel industry is firmly established in this country. Although the steel companies are quite willing that the bounties should be continued, it is evident from their prosperity that this continuation is not necessary. We may also affirm that the system of giving direct grants to encourage the establishment of basic industries in our country has been fully justified. These bounties have been paid for a term of several years, decreasing in amount each year, and finally terminating on December 31st last. Table 1 shows that the production of pig iron has steadily increased both in tonnage and value.

TABLE 1.

ANNUAL PRODUCTION OF PIG IRON BY PROVINCES, 1887–1909.

Year.	Nova Scotia.		Ontario.	
	Tons.	Value $	Tons.	Value $
1887	19,320	$250,000	.....	.....
1892	40,049	583,556	.....	.....
1897	22,500	230,000	26,115	$291,466
1902	237,244	2,477,767	112,688	1,584,273
1907	366,456	4,211,913	275,459	4,581,309
1908	352,642	3,554,540	271,484	4,385,271
1909	345,380	3,453,800	407,012	6,002,441
	Quebec.		Total.	
1887	5,507	116,192	24,827	366,192
1892	2,394	53,865	42,443	673,421
1897	9,392	217,235	58,007	738,701
1902	7,970	181,501	357,902	4,243,541
1907	10,047	232,004	651,962	9,125,226
1908	6,709	171,383	630,835	8,111,194
1909	4,770	125,623	757,162	9,581,864

From Table 2 it further appears that there has been an equally encouraging increase in the production of steel.

TABLE 2.

Annual Production of Steel Ingots and Castings 1897–1909.

Calendar Year	Short Tons.
1897	20,608
1902	203,881
1907	706,982
1908	588,763
1909	754,719

It must further be noted that we have made some small exports of both pig iron and steel.

To those who have not considered the subject it will perhaps be a matter of some surprise to note that Canada now ranks eighth among the nations of the world in her production of iron and steel. We have still a long distance to go, however, before overtaking the seventh country on the list, namely Belgium, as shown in Table 3 below.

TABLE 3.

Production of Pig Iron in the Principal Countries of the World.

	1908	1909
United States	16,191,907	26,209,677
Germany	11,805,321	12,625,575
United Kingdom	9,202,280	9,819,469
France	3,400,771	3,544,638
Russia	2,800,653	2,871,332
Austria-Hungary	1,518,549	
Belgium	1,270,050	1,632,350
Canada	572,290	686,893
Sweden	567,821	443,000
Spain	403,554	
Italy	112,924	207,800
China	66,409	74,000
Japan	45,396	
Australasia	30,393	

Nothwithstanding this gratifying increase in our production of iron and steel we are still very far from meeting our own requirements. Our imports of manufactured iron and steel goods are still enormous, as shown in Table 4.

TABLE 4.

	1908	1909
Imports of iron and steel subject to duty	$ 51,485,456	$ 33,083,397
Imports of iron and steel free of duty	10,334,242	7,310,034
Total imports	$ 61,819,698	$ 40,393,431

Many of these articles are highly manufactured and we can hardly expect that their production should be undertaken in Canada. The weight of these iron and steel manufactures is largely unknown. Included, however, in the figures presented in Table 4 are a large number of partially manufactured products which could be well made in Canada and of which the tonnage is known. These are given in detail in Table 5

TABLE 5.

Imports of some Iron and Steel Products of which the Quantities are Available.

Material	Twelve Months ending March 1908 Short Tons	Twelve Months ending March 1909 Short Tons
Pig Iron	212,290	58,591
Ferro-products and chrome steel	17,661	13,206
Ingots, blooms, billets, puddled bars, etc.	21,222	8,887
Scrap and scrap steel	69,213	26,212
Plates and sheets	126,172	101,317
Bars, rods, hoops, bands, etc.	98,631	69,818
Structural iron and steel	373,871	162,735
Rails and connexions	52,706	32,543
Pipes and fittings	25,090	18,309
Nails and spikes	2,741	1,432
Wire	57,046	39,452
Forgings, castings, and manufactures	22,357	13,092
Total	1,079,000	545,594

Although a study of Tables 1, 2 and 3 shows that the production of iron and steel is firmly established, it must be admitted that there are some discouraging features in the situation. Of the total quantity of ore required for Canadian furnaces in 1909, only 17% was of Canadian origin. All the furnaces in Ontario and Quebec are dependent on imported coal or coke and two of them are using imported limestone. As Ontario and Quebec are devoid of coal, the importation of fuel must be continued until such time as the further development of the electric process of smelting will enable us to substitute water power for a portion of this fuel. These facts are unpleasant; but they should be faced and a serious attempt made to develop our own resources.

A study of the last available statistics shows that iron ore was produced in 1909 in only two of our Provinces, as shown in Table 6.

TABLE 6.

PRODUCTION OF IRON ORE BY PROVINCES, 1907–8–9.

	1907		1908		1909	
Provinces	tons	value	tons	value	tons	value
Nova Scotia.	89,839	$137,161	11,802	$ 17,620	. . . .	
Quebec.	12,748	34,956	10,103	22,094	4,150	5,508
Ontario.	207,769	488,324	216,177	528,475	263,893	653,808
British Columbia. .	2,500	6,500	. . . .	. . . .	. . . .	
	312,856	666,941	238,082	568,189	268,043	659,316

In 1910 conditions were somewhat improved by a small production in both New Brunswick and Nova Scotia. Our steel industries in Nova Scotia utilize nearly altogether iron ore from Newfoundland. In the past a considerable tonnage of ore has been raised from Nova Scotian properties; but the cheapness of the Newfoundland ores has virtually excluded the Nova Scotian ore from the market.

In Ontario and Quebec our furnaces have been supplied in part from Ontario ore and to a small extent from Quebec ores; but much more largely by American ore from the Lake Superior region. This has been due in part to the cheapness with which American ores could be secured, since they are not subject to an import tax. It should further be noted that American ore-producers are willing to take contracts for the requirements of the furnaces and to deliver ores of the standard agreed on. So far there have been practically no producers of Canadian ore and those who were offering to deliver ores were undertaking the business in a most half-hearted way. Few of them were able to accept any considerable contract and from the smallness of their operations furnace men were afraid to entrust them with contracts. Moreover, the ore produced was apt to vary very much in grade and was frequently not of an attractive character.

Some of the iron and steel companies have been very active in looking for Canadian ores and have spent large sums in the search. It must be confessed that so far the results have been rather disappointing. Other companies have done little in this respect, probably for the reason that their capital was required in connection with their iron and steel plants. Practically no money is being spent in Ontario by independent ore companies, a fact, no doubt, partially attributable to the smallness of the market. While there was a duty of 40c a ton on Canadian ore entering the American market a producer of Canadian ore had very few furnaces with which he might market the ore. Owing to the different grades required by the different furnaces, and geographical conditions, it often happened that only one furnace was available. It is not surprising that miners have hesitated to embark in the production of iron ore with such a small market open to them. With the reduction of the American duty to 15c a ton this cause is partially removed.

In a number of the provinces there are no smelters, and iron ore unless within reasonable distance of a furnace is of no value. This observation particularly applies to British Columbia, where a number of promising deposits are known, but where there is no incentive to development because of the lack of a market. This is also true, though to a much lesser extent, of the prairie provinces.

TYPES OF IRON ORE DEPOSITS.

Before describing the various deposits of the different provinces it will be well to discuss the general types of iron ore deposits, their characteristics, origin, probable size and quality. The classification adopted is an original one which, it is hoped, is an improvement on those commonly employed:

Origin	Agency	Type	Sub-Type
Subterranean Origin	Igneous	1. Magmatic	1 (a) Magnetite 1 (b) Chromite 1 (c) Pyrrhotite
	Aqueo-Igneous	2. Pegmatite	
	Aqueous	3. Vein	
Superficial Origin with subsequent Burial in most Cases	Chemical Sediment	4. Carbonate	4 (a) Siderite 4 (b) Clay Iron-Stone 4 (c) Black Band
		5. Bedded Pyrite	
	Chemical Sediment or Alteration Product	6. Limonite	6 (a) Bog Ore 6 (b) Altered Carbonate, etc.
		7. Clinton Hematite	7 (a) Oolitic 7 (b) Altered Carbonate
	Altered Sediment	8. Lake Superior	8 (a) Soft Ore 8 (b) Hard Ore 8 (c) Siliceous Magnetite
		9. Metamorphic	
	Mechanical Sediment	10. Beach Sand	

This classification has the merit of showing the close connection in origin between the different types. "Natura non facit saltum." The magmatic type grades into the pegmatitic and that again into that of the true vein. It is but a step from carbonates, and sulphides, of iron deposited in veins through the action of heated waters, to the deposit of similar compounds as chemical sediments in shallow waters. Alteration of these sediments gives rise to limonite and hematite and magnetite. From all of the former, mechanical iron sediments may accumulate as Beach Sands.

1. *Magmatic Type.*—Deposits of this kind are due to the separation of the iron minerals from cooling basic igneous rocks. Magnetite is the most common iron mineral and usually carries titanium. The type is well represented by the titaniferous iron ores of Quebec. From a commercial standpoint this ore is at present useless. Changes in furnace practice and improved methods of concentration, will probably make it valuable in the future. The nickeliferous pyrrhotite of Sudbury also belongs to this class.

2. *Pegmatite Type.*—"Ores are carried to or near the surface in magmas and are extruded from them, in the manner of pegmatite dykes, after the remainder of the magma has been partially

cooled and crystalized." They are deposited from essentially acqueous solution mixed in varying proportions with solutions of quartz and silicates. Here belong a large number of contact deposits of magnetite which are found at the junction of a sedimentary rock, usually limestone, with an intrusive igneous one. The magnetite deposits in the coast region of British Columbia are excellent examples.

3. *Vein Type.*—Ores of iron occurring in veins and usually associated with more or less quartz. Iron occurs only in limited amounts in this type and then most frequently as iron sulphide. Some of the pyrite deposits of eastern Ontario belong here. Some narrow but lengthy veins of high grade hematite occurring north of Lake Huron belong in this type. Siderite and magnetite also occur in veins.

4. *Carbonate Type.*—This class of ore occurs in the Keewatin and Huronian iron ore formations of Lake Superior. Much of the high grade ore of the Lake Superior district is believed to be derived from the alteration of siderite. Great beds of it, still unaltered, are found in northern Ontario. As ankerite, a mixture of lime, magnesium and iron carbonate, this type of ore is found in the Palæozoic formations of Nova Scotia. As clay iron-stone this type occurs in nodular concretions in the Cretaceous shales of the west. In the coal horizons these ironstones become mixed with coal and are then known as black band.

5. *Pyrite Type.*—Associated with type 4 and type 8 in the Lake Superior district are frequent beds of iron pyrite, almost pure except for the silica which has been deposited with them. As a source of iron this type is of course useless and the low percentage of the sulphur which rarely rises above 40%, makes the type almost useless as a source of sulphur.

6. *Limonite Type.*—Bog ore deposits and similar varieties of this type are due to circulating surface water and vegetable acids which dissolve iron from the higher lands and deposit it again in bogs and lakes. Deposits are small in size but are unique in that they are renewed after an interval of a few years. Bog ores have been mined in Quebec for several centuries. The other sub-type of limonite ores is due to the weathering in place of ores of the carbonate (4) or pyrite (5) type. The oxidized carbonate ores of Londonderry, Nova Scotia, are an example.

7. *Clinton Hematite Type.*—"Clinton iron ore, so named from its typical occurrence at Clinton, New York, is an amorphous red hematite mixed with calcium carbonate, silica, aluminum silicate and other minerals in minor quantity. It occurs in lenticular beds analogous to the strata of sandstone, shale and limestone. This type occurs to a small extent in Nova Scotia and in more valuable deposits in Newfoundland. From its bedded and fairly uniform character the extent of deposits of this type is easily estimated.

8. *Lake Superior Bedded Type.*—"Ore is brought to the surface by igneous rocks and contributed either directly by hot magmatic waters to the ocean or later brought by surface waters under weathering to the ocean or other bodies of water, or by both; from the ocean it is deposited as a chemical sediment in the ordinary succession of sedimentary rocks." Frequently through the action of percolating surface water the original ores have been concentrated in impervious basins, the silica being at the same time removed by leaching. The original ores of this type usually consist of alternating bands a quarter of an inch to two inches thick of some form of silica with some iron mineral either iron silicate, iron carbonate, or iron sulphide. The solution and re-oxidation of such low grade ores have given rise to the large high grade deposits of the Lake Superior region. These oxidized and concentrated products may be a mixture of hematite and limonite soft in character and are then known as Soft Ores 8 (a). Subjected to pressure they become true hematites or magnetites or Hard Ores 8 (b). A typical example is the Helen Mine at Michipicoten. In some cases beds of considerable thickness are deposited with little or no silica, giving rise to beds included under types 4 and 5. In other cases the chemical precipitates of iron and silica have not alternated in bands; but have on the contrary been deposited together in beds up to several hundred feet in thickness. These beds under heat and pressure have been converted into low grade silicious magnetite 8 (c) of which large numbers of examples occur throughout northern Ontario. In a few cases the silica is low enough in amount to permit of the direct mining of these deposits, Moose Mountain and Atikokan Mine Ontario, being examples.

9. *Metamorphic Type.*—There are a large number of deposits of magnetite in North America usually classed under this heading.

Such a type should not be used in a strict genetic classification. It is, however, a convenient designation for many of the magnetite lenses found associated with gneisses and cystalline limestone in eastern Ontario and adjoining parts of Quebec. The ore bodies are not large, they conform to the stratification, they pnich out rapidly both horizontally and on the dip. Their origin is uncertain. They may be metamorphosed beds of siderite like the Lake Superior magnetites described under 8 (c). They may be metamorphosed beds of Beach Sands. In some cases these deposits may properly belong with the pegmatite type 2.

10. *Beach Sand Type.*—These deposits, nearly always magnetite, occur in beds varying from half an inch in thickness to several feet. Considerable bodies are known on the Lower St. Lawrence and on the north shore of Lake Superior. They are at present of no commercial importance.

BRITISH COLUMBIA.

Throughout the coast region of this province numerous deposits of magnetite are found which are high in iron and low in phosphorus. These deposits occur at the contact of igneous intrusives with some sedimentary rock, usually limestone. These deposits are very irregular in their outcrops and one cannot predict anything definite as to the size and shape of the ore bodies. They belong to deposits of the pegmatite type and presumably have a greater extension in depth than they have in either breadth or length. Usually a series of outcrops is found along the line of contact varying from a few square feet in area up to deposits one hundred and fifty feet wide and several hundred feet in length. Little is known as to their depth, though several deposits have been opened by tunnels to a depth of one hundred feet. At the Paxton Mine on Texada Island the ore is exposed by a tunnel for a width of seventy-five feet, at a depth of about five hundred feet from its highest outcropping on a hill above.

Most of these deposits carry a little sulphur in the form of pyrite or chalcopyrite. In many cases deposits of this type have sufficient copper value to make them attractive from this standpoint and they are operated as copper properties. With the increase in copper there is usually a decrease in iron contents.

There are many deposits throughout the coast region too low in both copper and iron to be worked for either.

A long list of these properties is described in the various reports of the Minister of Mines for British Columbia; particularly in that for 1902 (7). Lindeman (9) describes a number of the more important ones. Among these may be mentioned the deposits on the Gordon River, Texada Island, Campbell and Nimpkish Lake.

The average of all analyses on one of these groups of claims made by the writer yielded iron 56.135%, sulphur 1.34%, phosphorus .101%. On another property the analyses averaged 60.98% in iron, 1.8% in sulphur and .015% in phosphorus. The average of all analyses in three other private reports on different properties was as follows: iron 62.82%, sulphur 1.54%, phosphorus .028%: iron 68.79%, sulphur .35%, phosphorus .056%; iron 61.47%, sulphur .67%, phosphorus .021. The average of these different properties will probably fairly represent this class of ore. The average is iron 58.04%, sulphur 1.14%, phosphorus .044%.

It is estimated by Hayes that these deposits contain at least thirty million tons of ore of present commercial grade and probably a considerable larger amount of low grade and deep ore not now available. My own opinion is that considering the frequency with which this type of deposit has been found in the small area of the province which has been prospected that the total tonnage ultimately available will be much larger than this estimate. Practically only portions of Vancouver and Texada Islands are included in this estimate. Similar deposits are known in the Queen Charlotte Islands and on the Chilcat River, in the extreme northern part of the province. The main land is also likely to show numerous deposits of this class.

Clay ironstones of type 4 (b) are known to occur in the Queen Charlotte Islands and on Vancouver Island in connection with the coal deposits; but at present are of no commercial value. Possibly they may be of some use in forming a desirable mixture when the smelting of the magnetite is undertaken. At several points deposits of bog iron ore are known and although very great claims have been made as to the value of these deposits I think they may be considered useless at the present time. Some bodies of hematite are reported on Vancouver Island and on the main land near Bute Inlet but little is known of them. In south-eastern Kootenay, at Kitchener and Bull River, deposits of hematite have been partially explored (8).

The lack of smelters in British Columbia and the Pacific coast of the United States has been a serious drawback to the development of the British Columbian ores. Without a market the mine owner was not warranted in spending money on the development of his property. Per contra, iron men have hesitated to establish furnaces until a sufficient quantity of iron ore was assured them. The coming summer will probably see an end of this condition of affairs as two companies are now proposing to establish iron furnaces in the province.

Prairie Provinces.

Throughout Manitoba, Alberta and Saskatchewan almost no iron ore of commercial value is at present known. Naturally in the prairie parts rocky exposures are few and moreover the conditions for the formation of iron ore deposits are absent. In the Pre-Cambrian area, which touches the north western corners of Manitoba and Saskatchewan, iron deposits of the Lake Superior type will probably be found.

One such deposit is known on Black Island in the narrows of Lake Winnipeg. This has been described by Tyrrell (11) as a mass of hematite occurring along the shores for one hundred paces and rising to a height of seven feet above the water. The ore is a fairly pure hematite, not very compact at the exposed surface, and with numerous particles of calcite and quartzite. Metallic iron runs from 54% downwards; the ore is low in phosphorous and high in sulphur. As there is no market at present for this ore little exploration work has been done and this not of a character to determine the quantity and quality of ore available.

On Lake Athabasca Tyrrell (12) discovered what is apparently a large deposit of hematite. The ore occurs as a mixture of hematite with quartzite through several hills. The remoteness of the district has caused this discovery to pass unnoticed.

Clay ironstones of Type 4 are widely distributed through the three prairie provinces. They have been described as occurring in the valley of the Assiniboine River, in the vicinity of the Dirt Hills, at Red Deer River, on the LaBiche and elsewhere. These ores vary from 34% in iron downwards and are probably of no commercial value. Occasionally, where assorted by river action, small deposits occur which might be used by a furnace near at hand.

On the outer edge of the Rockies there are numerous occurrences of reddish shales of Triasic age, which in places carry considerable iron. Possibly some of these may yet prove of value as a source of iron ore.

Alberta, particularly on its west boundary, is very rich in coal of good coking quality. There is a large and ever increasing demand for pig iron in the three provinces for local foundry purposes. Such pig at present commands a very high price, due to the high freight charges on pig iron from the east. There does not, however, seem to be any available scource of iron ore within these provinces; but the hematite deposits of south-eastern British Columbia, if properly developed, may yield sufficient ore for a furnace situated in the Crow's Nest Pass.

The iron ores already known, and which may be found, in northeastern Manitoba and Saskatchewan are too far from a source of coke. With the development of the electro-thermic process for smelting iron ore these may, perhaps, become of value.

THE TERRITORIES.

In the Yukon Territory occurrences of magnetite similar to those occurring in the coast region of British Columbia are known. Cairnes (15) describes the Mack claim on the Hutshi River as "A small hill of almost solid iron ore about two hundred feet long." The Gilltana Lake claim consists of magnetite with more or less chalcopyrite as is so often found with these contact deposits of type 2.

On the head waters of the Wind, Bonnet Plume and Snake Rivers, tributaries of the Peel, Camsell (14) describes large quantities of float consisting of banded jasper with hematite or magnetite. On the Rackla, a tributary of the Yukon, Keele (14) finds similar float in large quantities. Apparently around the head waters of these streams there is a large area carrying banded jaspers similar to the Lake Superior type. The iron ore is of course of no commercial value at present and consequently no exploration has been undertaken.

Several occurrences of magnetite and hematite are reported on the islands of the archipelago in the district of Franklin (17).

In the district of MacKenzie specular hematite is reported to be found in the vicinity of Great Slave Lake. In the territory of Keewatin, magnetite, apparently of the Lake Superior type, is found near Knee Lake (18). On Berrens River, magnetite of similar character is reported (19) by Low. There are probably very numerous occurrences of the Lake Superior type stretching far to the north-west through the province of Keewatin. Close examination has not yet been made of this large area.

On Sutton Mill Lake, an expansion of Trout River, south of Hudson Bay, there is an exposure of the Animikie rocks similar in character to those at the west end of Lake Superior. Dowling (16) reports the occurrence of jaspilite interbanded with hematite and magnetite as in the region around Fort Arthur. The deposit observed by him occurs in narrow beds, the iron running from 68% down to 28%. It would seem probable that careful examination of these areas might lead to the discovery of iron ore of commercial value. The district is seventy miles from Hudson Bay.

In the territory of Ungava, banded jaspers are known in considerable quantities and commercial ore may yet be found. Leith (20), Low (21) and Mickle (13), together with others, have visited and described these rocks. The Nastapoka group consists of chemical and mechanical sediments closely related in appearance to the Animikie rocks of the Lake Superior basin. Interbedded with the shales and sandstones of this group are beds of jaspilite forty to one hundred feet in thickness. In these beds are occasional concentrations somewhat richer in iron ore. In the natural exposures few cases are found where less than half of the beds are rock and even of the balance there is considerable silica mixed with the iron ore. There are two types of occurrence, one of siliceous hematite or magnetite ore, and the other manganiferous carbonate ore. In both cases the local enrichment does not extend more than a few hundred feet in length or on the dip of the beds. The similarity of geological occurrence and of the enclosing rocks on the Nastapoka Islands and in the Mesabi district of Minnesota is striking. Whether commercial ore bodies will yet be discovered in the former can only be told by extensive exploration.

One hundred and twenty-five miles south of Ungava Bay, in the valley of the Koksoak, there is an occurrence of rocks apparently of Animikie age. For seventeen miles these rocks are exposed along the river valley from Shale Falls to the mouth of Swampy Bay River. Low (22) describes the ore bearing portion of these rocks as alternating bands of magnetite and jasper in close proximity to cherty limestone. Analyses of the ore run from 31% to 54% in metallic iron. On the natural exposures from which these samples were taken the ore is hardly of high enough grade to be of commercial value. Such as it is Low states that "The ore in sight must be reckoned by hundreds of millions of tons."

On the Ashuanipi Branch of the Hamilton River, three hundred miles due north of the Seven Islands on the north shore of the St. Lawrence, there is an occurrence of similar rocks. Through faulting four different belts of these rocks are exposed. The ore formation consists of banded magnetite or hematite with jasper and cherty limestone. Assays of natural outcrops showed iron varying from 30% to 40%. Low states (22) that "The deposits are wide-spread and that the ore will be found in practical inexhaustible quantity." The striking similarity of these last occurrences to several of the iron ranges of the Lake Superior district must be noted. Whether natural concentration of these ores has taken place can be proved by careful exploration. The large area over which the occurrence are found renders it probable that in some cases concentration will have occurred.

On the Stillwater River, in Ungava, Low reports a large area of iron-bearing ore in gneiss. Beds of impure iron ore are also reported from the shore of Hudson Strait.

Ontario.

The iron ores of Ontario have been the subject of numerous papers and for that reason only a brief summary will be given here. From the standpoint of the present demand for iron ore the deposits of Ontario are the most important in the Dominion and consequently are not receiving the space in this paper which their commercial importance would warrant. A consideration of the more remote portions of the Dominion has, however, taken so much time that I shall content myself here by referring the interested reader to other papers. In the eleventh volume of the Journal of this Institute, I published a paper on the Iron Ores of Ontario, which summarized fairly well the known occurrences of iron ore in Ontario. To those seeking more detailed information I would refer to the Index (23) to the Reports of the Bureau of Mines of Ontario 1891–1907.

Iron ores of the magmatic type are represented in Ontario by deposits at Nemogosenda on the Canadian Pacific Railway; at Bushnell on the Timiskaming and Northern Ontario Railway; at Gooderham on the Irondale Bancroft and Ottawa Railway and elsewhere. All of these ores are magnetite and most of them are contaminated with more or less titanium and frequently with sulphur. That at Nemogosenda has been worked this year and some others have been worked in the past. The pyrrhotite of Sudbury which carries the Ontario nickel belongs to this type.

The Pegmatite type is represented by such properties as the Belmont in Central Ontario. This is a magnetite, low in phosphorus, high in iron and with some sulphur. A number of deposits of a similar type are known through Eastern Ontario.

The Vein type are represented by a number of small and unimportant deposits occurring in the quartzites of the lower Huronian north of the Georgian Bay. Deposits of this kind are known in Aberdeen Township, near Algoma Mills and in the vicinity of Killarney.

The Carbonate type is represented by the siderite of Devonian age occurring on the Opazitika in Northern Ontario. Deposits of siderite of Keewatin age are found at the Helen Mine, Josephine Mine, Magpie Mine in the Michipicoten district and at Steep Rock Lake in the Rainy River district. These siderites run around 35% in iron, are very low in phosphorus and with some sulphur. They exist in considerable amounts and on roasting would yield a fairly good ore.

The most important ores of Ontario belong to the Lake Superior bedded type. They are restricted almost entirely to beds of Keewatin age and occur at scores of places throughout the province from the Manitoba boundary to the Ottawa River. The different ranges have been described by Miller (25) Coleman and Willmott (26), Coleman (27), Miller (28), Leith (29), Smith (30), Bell (31), Silver (32), Coleman (33), Coleman and Moore (34-35), MacKenzie (36), Moore (37), Allen (38). The formation consists of chert or jasper interbanded with hematite, magnetite, siderite, or pyrite. These beds are usually standing vertical and their total length within the province must amount to several hundred miles. The similarity between these ranges and the Vermilion iron range of Minnesota is very close. Natural concentrations are to be looked for in these iron formations and the ore, if found, will likely be deep. Comparatively little exploration has yet taken place on these Ontario ranges. It is probably safe to assert that there has been more exploration on the twenty-three miles of the Vermilion iron range than on the several hundred miles in Ontario.

There are four producing mines in Ontario located on this class of deposit namely: the Helen, Magpie, Atikokan and Moose Mountain mines. At least three other properties have been drilled with satisfactory results but have not yet been opened up.

The Limonite type is represented by a number of bog iron deposits in the older parts of the province which have been slightly exploited in years gone by. Some deposits of this character in the Metagami valley are the subject of a paper before the Institute this year.

The Metamorphic type are represented by many of the magnetite deposits along the Kingston and Pembroke Railway, which have been described by Ingall (39). Other deposits of this character have been worked along the lines of the Central Ontario Railway and the Irondale Bancroft and Ottawa Railway.

QUEBEC.

Iron ores of the Magmatic type are of frequent occurrence throughout the province of Quebec. Deposits at Bay St. Paul, Seven Islands, St. Jerome, St. Lin, Lake Kenogami and on the Chaudière are described by Ells (43). Many of these deposits are of large size and some of them are high in iron, all of them carry titanium and many of them in large amounts.

Deposits of the Beach Sand type are also of frequent occurrence in the Province. They are particularly abundant along the shores of the St. Lawrence, where they occur in beds from six inches to two feet in thickness. Among the more inportant are those at Moisee, Mingan, Bersimis, Tadousac, which are described by Ells (43).

Bog ore deposits are widely scattered throughout the province and have been mined in small quantities for many years. In the district of Three Rivers small furnaces have been at work for a long time using the local ore supplies. Bog ores have been mined in Drummond and Vaudreuil counties.

Ores of the Lake Superior bedded type do not seem to have been recognized to any large extent. Their occurrence has been noted on Lake Opazitika on the boundary between Ontario and Quebec and also near Lake Megantic in the southeastern corner of the province (44). As there are numerous areas of the Keewatin rocks throughout Quebec (usually mapped as Huronian in the Geological Survey reports) there is every reason to think that with proper prospecting many occurrences of this type will be found.

Ore of the Pegmatite type is found at a number of places, particularly in the counties of Pontiac and Ottawa. The Ironside Mine (40) and the Bristol Mine (42) have both produced a small amount of magnetic ore. Throughout the Eastern Townships a number of magnetite deposits are known in the townships of Brome, Sutton, St. Armand, and near Sherbrooke. These probably belong to the Metamorphic type.

A number of deposits of chromite are known in the Eastern Townships and some production takes place annually. They have been described by Cirkel (41).

NEW BRUNSWICK.

During 1910, iron mining in New Brunswick has taken on a new lease of life. This is due to the discovery and exploitation of some large deposits of iron ore near Bathurst by the Canadian Iron Corporation. These ores were described by Hardman (45) before the Institute two years ago. There are three separate areas, one of them two thousand one hundred and forty feet long proved to a depth of five hundred feet by drilling. Mr. Hardman estimated that half of these beds would average 53% iron and not over 15%

silica; phosphorus would be high, possibly .75%. The second area after hand sorting was expected to yield a product 58% in iron, 10% silica, 0.88% phosphorus and 0.055% sulphur. During the past year the property has been opened and machinery installed for the production of one thousand tons of crushed ore per day. A railway has been built and a dock completed at Newcastle, New Brunswick. Seven thousand tons of ore were shipped before the close of navigation. This ore belongs to the Lake Superior bedded type and seems closely related in origin to the deposits at Moose Mountain and Atikokan, Ontario.

Years ago some iron ore was mined in the county of Carleton and smelted locally. The ore is a hematite occurring in numerous veins one to sixteen feet in width. The ore was very low in iron and high in sulphur and phosphorus and the enterprise failed. Some small deposits of hematite are known in St. John county and some magnetite deposits in St. John and Carleton counties. These latter deposits have been described by Bailey (45). Bog ore is of frequent occurrence throughout the province but is not at present utilized.

NOVA SCOTIA.

Years ago Nova Scotia produced considerable iron ore; but the output diminished until it reached the vanishing point. Last year, however, witnessed a moderate revival of shipments. This decrease has been due to the ease and cheapness with which our eastern steel plants can procure suitable ore from Newfoundland.

The iron ores of Nova Scotia have been the subject of an exhaustive monograph by Woodman (47–48) published by the Mines Branch of the Department of Mines at Ottawa. According to Woodman the Nictaux-Torbrook basin is the most important and promising field in the province. The ores are Clinton hematites, and bedded magnetites metamorphosed from it. The ores occur in two zones striking north-east. On the north one are two ore bodies, the Leckie and the Shell, of economic value. The ores run 44% to 49% iron, 15% to 17% insoluble, .7% to .9% phosphorus and sulphur nearly .01%. The ore is used largely at Londonderry for mixing with local limonite and carbonate. The Clementsport district is regarded as a promising field for exploration. In Antigonish County are other Clinton hematites, which may be of value.

Along the Cobequid Hills, in Cumberland and Colchester counties, there are many isolated localities, in the Devonian where siderite and ankerite occur. In places these have altered to oxides at the surface, but rapidly changed into the unaltered carbonate in depth. Acadia Mines has been intermittently active for years as a mining and smelting centre. The ore is very low in phosphorus and sulphur and exceedingly low in iron.

SUMMARY.

No estimates of the amount of available iron ore in Canada have been made by any of the various Governmental officials. In a report by Hayes (4) on the Conservation of Natural Resources in the United States, an estimate is made of the iron ores in the countries adjoining the United States. The estimate is there made of available ore as follows: British Columbia thirty million tons, Ontario, nine million tons, Nova Scotia, four million tons, total, forty-three million tons. This I would consider a sufficiently high figure for ore already known. At the same time the possibilities and indeed probabilities are so great that a much larger tonnage must be considered as likely to be found. The Lake Superior type of bedded deposit is known to occur in the extreme north-west of our country in the Yukon territory and in the south-east in New Brunswick a distance of twenty-eight hundred miles. At numerous points between these extremes, Keewatin rocks of the great Archæan shield are known to occur and in nearly every case where these have been carefully searched the iron formation has been found. In far from all of these occurrences will the iron formation be productive of commercial ore but we have every reason to expect that with careful and detailed exploration many of them will. It is true that large areas at present are so far from transportation that they cannot be considered as possible sources of iron ore for years to come.

On either side of the shores of Hudson Bay the Archæan rocks are found much as they border both sides of Lake Superior. Already, with a most limited amount of exploration, we know that rocks of Keewatin and Huronian age are found bordering the shores of this inland sea and that these series of rocks carry the iron formations just as they do around the basin of Lake Superior.

Sixty years ago the production of iron ore on Lake Superior in the quantity in which it is produced to-day would have been looked on as an utter impossibility. It was urged that the district was so remote from supplies of coal that the ore even if found could not be profitably smelted. With the tremendous cheapening of transportation this has proved to be a false prophecy and it is quite possible that water carriage from Hudson Bay may yet solve the transportation problem for that great region. It should further be remembered that Hudson Bay itself is navigable for quite as long a period each year as Lake Superior.

In considering the possibilities of our great northern areas it would be well, also, to bear in mind what has been accomplished in Sweden during the last few years. Some of the largest deposits of iron ore in the world are now being mined in that country within the Arctic Circle. Geologically these ores occur in the Pre-Cambrian rocks found to such a large extent in our own country. The exact equivalent in type of ore deposits is at present not known here; but it is quite within the bounds of possibility that such may yet be found.

The Clinton ore deposits which yield such a large portion of iron ores of the United States occur but to a limited extent in Canada and cannot be looked on as probable large producers. In Newfoundland, however, two of our eastern steel companies have very large iron ore reserves in beds of this type.

LITERATURE.

References are given below to a number of the best papers treating of the iron ores of Canada. Many of the earlier papers have not been mentioned, as later papers have superseded them. In most cases these can be readily traced through the indexes to the various Government reports. Through the first two mentioned, descriptions of numerous occurrences of iron ore all over the Dominion can be found.

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SOME SUGGESTIVE PHASES OF THE IRON MINING INDUSTRY OF EASTERN NORTH AMERICA.

By FRANK L. NASON, West Haven, Conn.

(Annual Meeting, Quebec, 1911.)

In this paper strict accuracy, either as regards dates, tonnages or areas, has not been the aim. The object is not statistical in any sense of the word.

What are the salient historical phases of the iron industry of eastern North America? Do their phases point towards a definite line of future development? The answers to these questions are not submitted dogmatically, but suggestively.

The first record of the iron industry in North America is in the year 1608, when a few tons of iron ore were mined in Virginia and sent to England. Thirty-five tons were mined in that year. Three hundred years later, the United States alone produced 27,089,422 long tons of pig iron, corresponding to the production of about 54,198,844 tons of iron ore.

With the growth of the colonies, especially after the formation of the United States, iron mining and reduction extended from Maine to Alabama.

It is not necessary to recall these facts, other than that it suits the purpose of this paper.

It is a fact that the manufacture of iron, at this time, represented no advance in method; but was in every detail copied from methods in the old world. Water blast, catalan, charcoal forges, the raw iron forged into shape and the slag forced out by means of trip hammers, huge wooden beams with a mass of iron bolted or strapped on, beaten on an iron capped wooden anvil. Experiences, often disastrous experiences, taught that certain iron ores could not be used. Why was unknown. That catalan iron was good was testified by the fact that as late as 1880 such forges were in extensive use in Clinton County, New York.

The catalan forge was supplemented, not superseded, by blast furnaces. Bounded by almost the same geographic limits are massive stone stacks held togeher by timbetrs bolted in place.

In the first blast furnace, as in the older catalan forges, little or no advance had been made in the knowledge of ores; furnaces were charged on the basis of inductive, not at all on deductive reasoning. It is pathetic to us to-day (as our methods may be to those who come after us) to read that one furnace master insisted on the use of wooden shovels, that his charge must be mixed by a given number of turns to the right, a number of turns to the left, a peculiar twist of the shovel; all but, if these were not included, incantations, trade secrets these, to the end that a certain grade of iron might be produced. One ore was selected, another rejected, two or more ores were mixed, and the ratios of their mixtures were also guarded as a trade secret.

Of course, rich ores were a desideratum; but here, too, the sole guide was the eye. To be specific, many and more were the attempts to use the rich looking ores which we now know are high in titanium, and no distinctions could be made by the older iron workers between the titaniferous iron ores and the more tractable magnetites, save that one ore could be worked and the other could not. Still further were they puzzled by the fact that one deposit of magnetite could be worked and another could not, that some one part of a given deposit was impracticable, while another was suited to their ends.

Between the years 1840 and 1850 hot and cold short iron was ascertained to be caused by phosphorus and sulphur respectively, and a distinction was first made between titaniferous and non-titaniferous iron ores. It was at this date that chemistry took the place of wooden shovels and incantations and made it possible to charge furnaces by chemical formulae and thus to control the product. Whatever the exact date, whoever the man or nation, the introduction of chemistry marks one of the most important forward steps in this great industry.

Before 1860, the growing demand for iron products had been met by extensive rather than intensive methods. In other words, two new catalan forges or two new stone stacks were built instead of enlarging the capacity of any one. About this time, 7 to 14 tons of iron was the weekly limit of a single forge, and 100 tons weekly the output of the blast furnace. Both were dependent upon charcoal as fuel. Again, at about this date, two other remarkable advances were made, the one practically dependent upon the other. The old blast furnace was limited in capacity by two factors: There were no water-jacket, fire-brick lined structures; resistance to heat and burden was met by thick, trussed stone walls. Subjected to extremes of heat, unequal contractions and expansions practically limited the capacity of the furnace. Even had this difficulty been eliminated, there remained the unavoidable fact that even the best of charcoal would not hold the heavier burden of the charge whch a larger capacity furnace would entail.

The introduction of the hot blast, the use of brick lined iron stacks, the substitution, first of anthracite and, later, of coke, for charcoal, gradually but rapidly increased the output of these furnaces from 100 tons to over 3,000 tons weekly. Attention may first be directed to the good offices of the chemist in pointing out that the difference between pig iron and wrought iron was mainly in the percentage of carbon, and that carbon could be eliminated by puddling. The increased output and the discovery that puddled pig iron was cheaper many times than the catalan iron, practically sounded the death knell of the catalan forge.

Again, attention is called to the fact that in 1870 pig iron sold at from $70 to $100 per ton, against $10 to $22 to-day, and that iron rails were imported at a cost of from $150 to $250 a ton. At about this date, moreover, the Bessemer process, patented in 1856, was introduced into the United States. In the year 1870, the total production of iron ore was 5,302,852 tons; in 1880 7,487,509; in 1890 14,518,857 tons. Of course, the Bessemer process was not wholly responsible for this increased production; but without it, the tremendous development of our railroad systems would have been financially impossible.

Not assuming a lack of knowledge on the part of the members of the Institute, but for purposes of his own, the writer desires to refer to some of the limitations of this process. In the republic of steel, phosphorus is an "undesirable citizen." In the Bessemer process the ratio of phosphorus to iron is not lessened. It is actually increased. Therefore in the old acid lined Bessemer converter phosphorus in the charge must be below the point of toleration in the finished product. This, of course, demanded low phosphorus ores, ores with less than .04% .09% of phosphorus. These were rare and were soon practically exhausted.

The process was modified by the Basic-Bessemer, where the lining of the converter was a base instead of an acid. This widened the range of phosphorus somewhat; but even this did not correspondingly increase the tonnage of available ores. Stated succinctly, the limit of slagging the phosphorus is the limit of the blow. When the carbon of the charge is burned off, the air oxidizes the iron and, whether the phosphorus is eliminated to the point of toleration or not, the operation must cease.

That this is so, is demonstrated by the fact that even the basic-Bessemer converter, making, as it doubly does, the best steel and the cheapest steel for rail and structural purposes, is doomed, *unless* there is a way opened to obviate its limitations. The only way seems to be a Bessemer ore, and to-day this is not to be had in quantities to meet the growing demand. The substitute for this process is the open hearth. Here there is no imperative time limit, as in the Bessemer converter. With a basic lining and a reducing, or at least a neutral, heat, phosphorus to any extent can be slagged off. But time is a valuable element here, as elsewhere, and is no respecter of chemical laws. Two per cent. of phosphoric acid demands 2.6 times as much of calcium oxide, and time must be consumed in forming the calcium phosphate. Consequently, even in the open hearth furnace, the lowest possible amount of phosphorus is desirable. The open hearth furnace is not a natural but a forced substitute for the Bessemer converter. There is no need, even for my purpose, to point out the many attempts to neutralize the effects of the element which it is so imperative and so difficult to eliminate. Vanadium, molybdenum and other alloys have been tried; but, if for no other reason than increased cost, the attempts so far, seem to have failed.

To sum up briefly, the striking, really epoch-making phases of our iron industry are the introduction of hot-blast; anthracite and coke; brick-lined, water-cooled iron stacks; chemistry; the Gayley dry air blast; puddling pig iron; the Bessemer; the basic-Bessemer, and finally, now, the open hearth furnaces. I purposely omit, for the present, the recently introduced electric furnace, in which Canada has taken such a prominent and intelligent interest.

The crux of the situation so far is this. The greatest invention or discovery in the whole range of steel making has not only been halted, but apparently defeated, by an unconquerable foe —phosphorus in the iron ores.

Is there any suggestion in past history that will tend to re-establish the Bessemer process, to supplement it or to make an acceptable substitute?

Passing now to a review of the iron ore situation:

Iron ores are classed as follows:—

Red hematite, with the formula Fe_2O_3.
Brown hematite in all degrees of hydration.
Magnetites, formula Fe_3O_4.
Carbonates, with their various types.

Titaniferous iron ores are not here given, since to-day they are not available as ores. As late as 1870 the Appalachian region produced 3,546,513 tons of iron ore, while the western or middle-west States, Michigan, Ohio and Wisconsin, produced only 1,593,489 tons. Attention is here called to two striking facts: Alabama in this year produced only 11,350 tons. Minnesota was unheard of.

Up to 1880 the Appalachian region more than held its own, with a total production of 5,667,348 tons, against 2,819,902 tons of the Lake Superior region. Of the Appalachian region, New York, Pennsylvania and New Jersey produced over 3,700,000 tons.

The varieties produced were as follows:—

Brown hematite........	27.70%	of the total.
Red hematite	31.54%	" "
Magnetite............	30.02%	" "
Carbonate	11.43%	" "

This was in 1880.

In 1906 the percentages were changed as follows:—

Red hematite	89%
Brown hematite........	5.8%
Magnetite.............	5.2%

It is certain that Michigan and Wisconsin produced hard hematite ore, while the product of Minnesota is largely soft red hematite. In 1906 Minnesota ores were produced to the extent of 25,359,077 tons, in which average phosphorus was .039; while the peninsula ores, 12,400,000 tons, averaged .103%. The average is arithmetical, not computed by tons.

During this year 1906, Alabama produced 821,301 tons of brown and 3,173,797 tons of red hematite. These ores are too high in phosphorus for either basic or Bessemer pig.

These facts are mentioned in order to emphasize the statement that unless some means of eliminating phosphorus is devised, the Bessemer process is doomed. From 1903 to 1906, inclusive, the production of Bessemer steel increased, in round numbers only 5%, while during the same period the production of open hearth steel increased 100%.

There is more than a suggestion in the preceding paragraphs. Unless low phosphorus ores are abundantly produced, the Bessemer converter is dead. Is there any prospect for such ores?

To avoid misunderstanding it should be added that the Bessemer process is not yet dead—on the contrary, it is still in robust health; but as individuals in good health and in middle life usually show to an expert diagnostician, signs of weakened organs, which will ultimately slay them, so with this individual process.

In the United States in 1906, the production of steel rails was 3,624,026 tons. In 1907 the rail production was practically the same. In 1907, however, 90% of the product was Bessemer steel. In 1909 the Bessemer product dropped to 58%. In 1910 it dropped to 52.8%. The loss in four years is 40%.

The edge may be taken from the above figures somewhat by the modifying statement that Gary, Bethlehem and Ensley with their recent installations of open hearth plants are responsible for this; but one is bound to ask, "Why?"

Would the quarrel between rail makers and rail buyers over specifications as to phosphorus have arisen and resulted in a change to open hearth unless something was radically wrong? Whatever the answer, these are facts. Low phosphorus ores are growing less with a greater demand, and the basic-Bessemer process has a fixed phosphorus limit beyond which it cannot go.

ORES.

The iron industry of the future will undoubtedly lie in two classes of ores—the red hematites, including the Clinton ores; the magnetites, including titaniferous iron ores. This may appear as a bold prophecy, in view of the fact that to-day the magnetic iron ores are slightly below the brown hematites, and are only 5% of the total production. If, however, we place two striking facts in juxtaposition, the prophecy will not appear so daring. In 1880, magnetic iron ore was 30% of the total; in 1884 the first shipment of ore was made from the Minnesota field. In considering this point, the structural characteristics of the various classes of ore bodies must be considered. The brown ores are, roughly, the results of leaching and redeposition, or are residual. The soft hematites of Minnesota are mainly residual; possibly leaching and redeposition have played a part as well. Both are thus similar in a highly important way. They are natural concentrates, are confined to surface phenomena of weathering, and are dependent on the slow disintegration of surface rocks and assemblage by means of meteoric waters. However extensive any one deposit or series of deposits may be, they are still limited, but variably as to depth.

The Clinton red hematites are, in the judgment of students of these ores, contemporaneous with the enclosing rocks, and for all that is positively known to the contrary, are co-extensive with this geological formation. The straight magnetites, *i.e.*, the non-titaniferous magnetites, are not so conclusively contemporaneous with the enclosing rocks. Opinions differ widely upon this point; but the fact remains that they are co-extensive, on the Atlantic seaboard, with the Archæan age. They are, however, not confined exclusively to this geological age, but reach through in lessened extent, the Cambrian, Ordovician and Silurian ages. There is this difference. In the Archæan—to retain an old term—the rocks are all highly crystalline and contain only crystalline ores, hematites or magnetites, while later geological formations have both carbonates, hematites or magnetites depending wholly on local metamorphism.

This, then, is practically true. The brown hematites and many red hematites have no fixed geological habitation and have decided limitations in extent; while the Clinton ores and the magnetites have decided habitats and, save for the rocks in which they occur, there is no one who can set a limit, areally or in depth, to their extent.

THE CHEMICAL CHARACTERISTICS OF THESE ORES.

The brown hematites typically contain 85.5% iron sesequioxide and 14.5% of water. But, except in rare instances, never in great quantity, do they conform to this type. Instead of theoretical 60% of iron, the working average is 40%, or lower, to 50%. In all cases they are comparatively high in silica, alumina and phosphorus and, in some instances, sulphur.

As mined, as a rule, they are totally unfit for furnace charges. They must be washed artificially, in some instances, the final ore is only 25% of the total mined. The remaining impurities are so intimately mixed with the ore that no degree of washing will free the ore from impurities. With log washers and jigs is thus the end of ore refinement.

With the Clinton ores, and to a certain extent, the Oriskany, much the same chemical condition obtains, save that in the worked deposits so much lime is present the ores are self-fluxing. The term "worked" deposits is advisedly employed. At Birmingham, Ala., the worked ore bed varies from 4′ to 25′, and this is practically self-fluxing. At the same place, however, outcrops of Clinton ore are to be seen 50′ to 75′ thick, the percentage of iron being higher, if anything; but here lime is almost wholly absent, and silica more than takes its place. While the Clinton ores are strictly hematites which theoretically contain 72% metallic iron, the average iron charged into the furnace averages 33% to 36%. The impurities are silica, alumina, calcium carbonates and phosphorus.

The structure of these ores, as in the case of the brown hematites, forbids concentration. Oolitic, formed in concentric layers when pure, more often they radiate concentrically around a grain of sand, a particle of limestone, a minute fossil shell, or seem to be precipitated from solution by algæ. Even were it possible to obtain, by grinding and concentration, a high iron ore, the loss would be quite out of proportion to the gain.

This is the inevitable conclusion. With the Clinton iron ores, as with the brown hematites, so far as we can see, we must always use these ores as they are or not at all. The ores are earthy and non-crystalline. and this is equally true of their impurities.

In the case of magnetic ores, this last condition is completely reversed. Not only is the rock habitat holo-crystalline, but the ores and the gangue as well. There are degrees of crystallization in rock and ore, but in these ores especially, vary from fine grained, dense and tough, to coarse, porous and friable.

Phosphorus invariably occurs as phosphate of lime in crystals or crystalline grains; more rarely, as a thin plating on the crystalline grains of magnetite. Feldspar, hornblende, pyroxene, biotite and free silica occur also as crystals or crystalline grains.

Sulphur occurs, when it does occur, as pyrite, chalcopyrite, or occasionally as pyrrhotite. As a rule, the leaner the ore, the more granular the structure of ore and gangue. Rarely does it happen that a considerable percentage of the iron, as magnetite, is included in minute grains in limpid quartz so completely that no economic degree of crushing will break gangue and mineral free.

This, however, is to be noted. In some very extensive deposits of magnetic ores, grains of so-called martite exist, and to the unaided eye are not to be distinguished from the magnetite. This martite is supposed to originate *in situ* by the oxidation of magnetite to hematite.

In considering magnetic concentration, this is a fact that must be taken into account, since martite is non-magnetic and so will pass off with the gangue. This is an important fact to consider.

The ores as mined areally vary from the theoretical limit of 72.4% of iron to 45%. The size of these richer deposits is variable. One deposit with which the writer is familiar has to date produced 25,000,000 tons of 60% ore. From this extreme we drop to lenses of a few hundred tons. The general average of shipped magnetic ore is about 55% iron.

Almost invariably, mining confined to these richer lenses is necessarily expensive. Lower ore specification from 60% to 40%, and the tonnage of a given district may be increased over 300%.

Almost invariably as mined, phosphorus puts these ores out of the steel class. To sum up briefly, magnetic iron ore averages no higher grade than the brown hematites and Clinton ores, but differ in that the hematites as a rule are non-crystalline and earthy, ore and gangue, while with the magnetites the reverse is invariably true. But the magnetites possess the decided advantage that the ores are highly magnetic, except as noted, while the gangue is always practically inert. It thus follows that while by no mechanical means, *at any cost*, can the hematites be concentrated, without great loss in volume, to anywhere near the theoretical limit of iron, there is no magnetic ore that cannot be concentrated to 70 or even 72%, and with a practically complete elimination of phorphorus. It depends wholly on what the ultimate concentrates will bring, and this has been and is, and probably always will, be the only limit. With one ore, concentration is only limited by comparative cost; with the other it is physically impossible.

This is one of the main suggestions, as it appeals to the writer, that the past makes to the future. Magnetic iron ores will regain their former supremacy and will hold it. Further, experience teaches that brown hematites are strictly limited in extent, and both brown and red show a tendency to grow uneconomically lean with depth, and with no hope of mechanical concentration, magnetites areally and in depth maintain their essential characteristics.

But this supremacy, of necessity depends on other factors than peculiar amenability to concentration or purification.

WHAT IS THE COMPARATIVE AREAL EXTENT OF THESE ORES?

The following figures are only crude approximations, but the linear distances are but little exaggerated; the ratio of mineralization no one can state exactly. The linear outcrops of magnetite ore-bearing rocks, in which large areas of magnetite ores, lean and rich, are known to occur, are as follows:—

Minnesota, East and West.............	160	miles.
Michigan and Wisconsin, East and West	475	"
Labrador to Alabama, N.E.–S.W.	2,400	"
Dominion of Canada, East and West ...	1,470	"
Total miles of Outcrop	4,505	

These linear dimensions are only a re-statement in another form of the fact that the old Laurentian formation is "Y" shaped; the tail of the "Y", the Appalachian mountains; the fork, on either side of the St. Lawrence. This is the old Archæan or Laurentian of classic geology, and in this extensive formation occur the magnetic and titaniferous iron ores.

CLINTON IRON OUTCROPS.

Ohio and Alabama	850	miles
Ohio and Minnesota.	570	"
Newfoundland..................	125	"
Total miles................	1,645	

Roughly, then, 84% of the magnetic iron ore outcrops on the Atlantic seaboard, and 66% of the Clinton ores, lies within the lines above given.

Geologically, there is no disputing the above figures.

The Appalachian uplift is the oldest, its rocks are wholly crystalline, and magnetic iron ores are almost exclusively confined to their rocks. The red hematites of Minnesota are purposely ignored. Twenty years ago iron mining practically migrated to to this state. Like many other adventurers, within twenty years it will return to the east. This is another important suggestion. In the main, this is true. At the outset Minnesota shipped 65% to 68% low phosphorus, low silica ores; to-day the base is 59% iron, and shipments are made below 55% . Silica is rising proportionately, as well as phosphorus, and there are no known mechanical means for essentially raising the grade of iron or lowering phosphorus and silica. Besides this, as has been pointed out, the very nature of the ores precludes hope of extensive depth.

CONCENTRATION.

Reverting again to this subject for a moment:

From the very earliest available records we learn of the concentration of iron ores, to a greater or less extent; the brown ores were cleansed by means of hand jigs and sluices. There has been no improvement in methods, only in mechanism. From the nature of the case, these methods alone are possible. I believe experiments have been made in partially deoxidizing hematites to the point of amenability to magnetic treatment; but it is not employed to-day. There appear to me to be many mechanical lions in this path. Magnetic concentration of magnetites is as old as the iron mining industry. It has only recently become a commercial success.

What follows is made as no hostile criticism of workers in the field of magnetic concentration; but as a suggestion merely.

The first point is the consideration of titaniferous iron ores. Little is known as to the volume of these ores, *i.e.*, the third dimension especially, since for years past, as to-day, they are regarded as impossible in a blast furnace. Contrary to the general impression, they are not universally low phosphorus, but range almost as straight magnetites. The same is true as to sulphur. All their impurities are crystalline, but, as in magnetites, the ores vary in grain and density.

There have been many attempts to concentrate these ores magnetically, but, as one leading metallurgist casually remarked, "The best that has ever been done is to part the ores in the middle." In other words, while silica, alumina and phosphorus were economically lowered, the titanium-iron ratio remained about the same, while, as he expressed it, "the loss of iron in the tailings was scandalous."

In handling these ores it should be remembered that they are mechanical, not chemical, mixtures of magnetite and ilmenite and that ilmenite carries 31.6% titanium and 36.8% iron. From this fact two lessons should be fairly well learned. First—that in ridding the titaniferous ore of titanium 1.16 points of iron must go with every point of titanium rejected. Second—If analysis shows from 37% Fe. and 48% Ti. the ore is a pure ilmenite, and attempt at magnetic concentration is foredoomed to failure. In an ore carrying 25% of titanium the loss is bound to be 28%

iron if titanium is completely eliminated, which it never can be. And for this reason:—the two minerals are mechanical mixtures and can never be mechanically broken apart. Therefore, in magnetic separation more or less titanium will be retained in the heads, and consequently more or less straight magnetite will be lost in the tails.

Though far less magnetic than magnetite, it is still magnetic and thus, with suitable machines, can be cleaned to the same degree of purity as magnetite; that is, all impurities can be rejected.

Yet, as in the case of magnetites, there are many titaniferous iron ores so fine grained and dense as to make it economically impossible to break gangue and ore apart to where they can be separated.

The point of concentration of titaniferous iron ores is elaborated for three reasons, the first of which is that, in spite of the lack of definite knowledge, expressed in terms of "vast," "immense" and "inexhaustible" (expressions which cannot be interpreted in cubic feet), it yet remains a fact that titaniferous ores are widely distributed. They are remarkably co-extensive with the magnetites and are usually more highly concentrated than iron ores in general, and to my personal knowledge, there are deposits which contain 25 to 100,000,000 tons.

My second reason is that for certain purposes, such as rails, titanium alloys appear to stand far ahead in low cost and high efficiency of any other steel alloy.

Thirdly—and this is eminently a suggestion—the electric furnace seems to promise to remove "direct steel" from the class of idle dreams and put it in the direct path that leads to economic facts accomplished. In this case it appears that titanium alloys may possibly be made direct from the ores.

It has been indicated that magnetic iron ores can be concentrated to almost complete purity, *i.e.*, to 68% to 70%. This is possibly not economic. Yet 60%, 65% and 66% concentration at a milling cost of from 40 to 75 cents a ton for concentrates is not only possible, but is actually a fact, and on a large commercial scale and over 90% saving of original iron is made.

Whether concentration up to 70%, which is practically possible and with 90% or more recovery, will be economic or not depends wholly on the relative costs of mechanical concentration, fine grinding, magnetic separation, and chemical concentration (that is the blast furnace). Chemical separation must be the final step to rid the ore of oxygen, and the critical point lies between 16% and 0% of impurities.

The second point is degree of comminution. In this the blast furnace has its limits. Comminution to the point where complete elimination of impurities is possible in fine grained ores makes an impossible furnace charge without briquetting the concentrates. With extremely fine concentrates, though, these ores are then in the best possible condition for rapid reduction, the necessary blast is obstructed and loss entailed from "blowing over."

In the electric furnace no blast is necessary, no fuel required, except the minimum amount of carbon to burn off the oxygen of the ores. There is possible in these furnaces the highest temperatures and any atmosphere necessity may call for.

Judging from the comparative areas of coal and metallic ores, under present metallurgical methods, our fuels will be exhausted centuries before the exhaustion of ore supplies. The minimum amount of fuel is required for actual reduction; the maximum amount is required to raise and to maintain the necessary reduction temperature. That the greater part of this is wasted no one will deny.

Can this necessary temperature be more economically obtained and thus conserve our fuels? Water power appeals to me as being the one solution to-day. In this connection it is suggested that electro-thermal units are regarded as being more expensive than carbo-thermal. They are now compared with the cost of coal burning, steam generating plants plus fluctuating price of coal. But a hydro-electric plant, once installed, its energy costs nothing save interest and repairs.

The Appalachian mountain system is well watered. The necessary head is suggested rather than detailed below.

The difference in level between Lake Superior and Lake Huron, 21′; between Lake Erie and Lake Ontario is 326′; between Ontario and Montreal about 250′ to 300′. The head waters of the Ottawa are about 800′ above Montreal. Lake St. John is about 346′ above tide. In general the Labrador peninsula is

1,300′ to 2,000′ above tide. In general also, the height of land of the Canadian North West Territory is about 700′ to 800′ above tide. The point is suggested that the 70′ tides in the Bay of Fundy and Ungava Bay will more than equal the power of the drainage sheds to which reference has been made.

In the United States the waters of the Appalachian mountain system drain into numerous small streams which unite with large rivers in the Piedmont plains, where volume is large and fall insignificant. To offset this, contiguous to this mountain system are our greatest coalfields.

But in this great Laurentian system from Labrador to Alabama is the greatest magnetic iron ore field known in the Western Hemisphere.

To sum up: It appears as a logical, if not an immediate, conclusion, having regard to the foregoing statements, that the development of the electric furnace and the abundance of magnetic iron ores, capable of the maximum degree of concentration, will bring iron mining back to the Atlantic seaboard, and bring it back to stay. The salient facts are these:

The Bessemer converter was an epoch maker. The electric furnace may either supplement it or supplant it. Both require rich, phosphorus free ores, whether natural or artificial. The natural ores do not exist. Magnetic iron ores are practically the only ones that can be refined economically to near the theoretic limit. These ores occur most extensively on the Atlantic seaboard. On the Atlantic seaboard are our greatest coalfields and our greatest water powers.

Even if the electric furnace fails to develop direct steel, the practical elimination of phosphorus from magnetic iron ores will restore the Bessemer converter to its former supremacy.

These facts—the diminishing grade and quantity of the lake ores, their lack of amenability to concentration, the great areas of magnetic ores, their amenability to complete mechanical purification, their location on the Atlantic seaboard, their proximity to the greatest coalfields and waterpowers—these seem to point to the return of iron mining to the East, to the rehabilitation of the Bessemer converter and the great development of the electric furnace.

THE WABANA IRON MINES OF THE NOVA SCOTIA STEEL AND COAL COMPANY LIMITED.

By THOMAS CANTLEY, New Glasgow, N.S.

(Annual Meeting, Quebec, 1911).

During the summer of 1895, when the mines on Bell Island were being opened and preparations made for large shipments of ore, the writer was given the privilege of putting a new name on the World's Commercial Map. He chose for this locality the Indian word "Wabana," a literal translation of which would be "The place where daylight first appears"—"The eastermost place on the Continent," the root words being "Waban" light or "bright," and "Wobun"—"daylight."

The first systematic treatise upon the geology of Newfoundland, is that by Jukes, published in 1858. This report alludes to Bell Island and its fertility, and also mentions that "two beds of red sandstone" are noticeable in its cliffs from the sea. This is the first reference known to have been made to Wabana ore, for at any considerable distance what is really red hematite may readily be mistaken for red sandstone.

Again, in the Report of the Newfoundland Geological Survey, for 1868, tabulated measurements are given of the stratigraphy of Bell Island, but no mention is made whatever of the outcropping of any ore body.

Eventually the value of the property being realized it was acquired by Messrs. Butler, of Topsail, from whom it was purchased by the Nova Scotia Steel Company in 1893.

The installation of a mining plant, tramway, and pier was then inaugurated, and on Christmas Day, 1895, the first shipment of ore was made to Ferrona, Nova Scotia; since which date an increasingly large output has been maintained.

In 1899 a portion of the areas was sold to the then recently formed Dominion Iron and Steel Company, the latter thus acquiring the lower bed while the Nova Scotia Company reserved for themselves the upper bed, the ore in which contains a higher percentage of iron than any of the other seams. This sale included a submarine area of about three square miles adjoining the shore. Subsequently the Nova Scotia Company acquired outlying submarine areas which it was believed would be workable because of the increased thickness of cover. The well known persistence of the beds also led to the belief that this submarine area would contain all the beds outcropping on the land.

Upon the submarine areas each Company own all the beds upon the respective claims, while on the land the Nova Scotia Steel and Coal Company operate the "Scotia" or upper bed, the Dominion Company working the underlying seam.

As the work progressed, additional areas were secured; and, at the present time, the Nova Scotia Steel and Coal Company own 32½ square miles of the submarine areas within the supposed limits of the basin, and the Dominion Iron and Steel Company, 8½ square miles.

To reach the Scotia submarine areas, it was necessary to pass through the Dominion areas referred to above, which, adjoining the land, extend almost 4,000 feet to the deep. An agreement was made by which slopes could be driven through these intervening areas and work was commenced accordingly in March, 1905. This work progressed favourably and the Scotia submarine areas were reached in 1909. (See Fig. 4). As the slope proceeded it was ascertained by diamond drilling that the lower bed had increased very greatly both in thickness and richness. At the outcrop this seam was eleven feet thick, but gradually increased to over double that thickness—indeed, in places to over 30 feet; while analysis of the ore showed that the iron-content was higher and the silica correspondingly lower.

In view of the remarkable increase in value of the lower bed, the Company decided to operate both it and the upper bed; and in March, 1910, the grade of the slope was accordingly increased to 30 degrees until the ore of the lower bed was entered in December, 1910.

The following table gives the ore mined and shipped by the Scotia Company to December 31st, 1910.

ORE MINED BY SCOTIA COMPANY TO DATE AND ITS DISTRIBUTION.

Year	Nova Scotia	United States	Germany	Great Britain	Total Shipments for Year	Total to Date
1895. ..	2,400	....	....	....	2,400	2,400
1896. ..	15,545	20,355	....	....	35,900	38,300
1897. ..	10,842	29,499	2,523	2,523	45,387	83,687
1898. ..	30,913	....	63,468	6,746	101,127	184,814
1899. ..	23,492	87,933	173,760	17,599	302,784	487,598
1900. ..	33,200	137,381	....	13,193	183,774	671,372
1901. ..	25,214	75,261	189,957	52,206	342,638	1,014,010
1902. ..	31,725	86,341	207,923	96,917	422,906	1,436,916
1903. ..	26,927	80,992	173,339	62,069	343,327	1,780,243
1904. ..	86,162	5,380	119,624	34,767	245,933	2,026,176
1905. ..	79,140	5,795	218,868	4,241	308,044	2,334,220
1906. ..	74,800	126,655	124,757	61,629	387,841	2,722,061
1907. ..	110,870	110,689	85,331	63,842	370,732	3,092,793
1908. ..	81,040	53,154	142,111	36,490	312,795	3,405,588
1909. ..	91,700	215,364	91,542	61,781	460,387	3,865,975
1910. ..	129,501	220,836	138,306	43,415	532,058	4,398,033
	853,471	1,255,635	1,731,509	557,418		

GEOGRAPHY.

Conception Bay is the most southerly, and one of the most important, coast waters in the northeast coast of Newfoundland. (See Fig. 5). It occupies an inlet in the northern part of the Avelon Peninsula, which is the most easterly part not only of Newfoundland, but of the American Continent. This arm of the sea projects into the land in a general southwesterly direction for about twenty-six miles, and has a maximum width of thirteen miles. It contains three principal islands, lying near the southern shore, known as Great Bell Island, Kelly's Island, and Little Bell Island. The first named, and the largest of the group, is about six miles long and two miles wide, with its longer axis lying northeast and southwest, and containing twelve square miles. It is on the north shore of this Island that the mining district of Wabana is situated.

St. John's, the capital of the colony, is distant thirty-five miles by water, and as the crow flies, thirteen miles. Easy access to Wabana from St. John's is afforded by a drive of ten miles over the hills to Portugal Cove on the south shore of Conception Bay, from which point a steam-ferry plies to the Wabana piers.

Upon glancing at the map it will be seen that the mines are thus directly upon the marine track of North Atlantic shipping. This is an extremely important feature, for perhaps the most necessary requirement for an iron property, after the quality and quantity of the ore shall have been assured, is its geographical position. Indeed, accessibility is fundamental. From Wabana, situated midway between Europe and America, the seaboard markets of both continents lie open.

The appended table of distances well illustrates this point:—

WABANA TO

	Miles		Miles
Rotterdam	2,294	Baltimore	1,398
Amsterdam	2,310	Philadelphia	1,242
Emden	2,475	New York	1,110
Glasgow	1,899	Boston	907
Liverpool	1,966	Buenos Ayres	5,658
Newcastle	2,406	Rio Janeiro	4,568
Middlesbrough	2,350	Panama	2,921
Stettin	2,633	Bermuda	1,160
Parambuco	3,518	Cape Town	6,245
Cape Race	100	Halifax	580
Sydney	412	Pictou	540
Quebec	930	St. John, N.B	867
Montreal	1,065		

GEOLOGY.

The geology of the area has been described in papers already contributed to the Transactions of the Institute.*

THE ORE BEDS.

Interstratified with the shale and sandstone, which compose the structure of the Island, there are on the north side of the Island six bands of ore ranging from one to fourteen feet in thickness. (See Fig. 2). Only the three uppermost beds, which are also the thickest, are at present mined. Of these, the lower (No. 4 in Fig. 2) and the little upper bed average, in the land areas, twelve

*A Newfoundland Iron Deposit: Chambers, R. E. Jour. Fed. C. M. I., Vol. I. p. 41, 1896.

See also. The Sinking of the Wabana Submarine Slopes: Chambers, R. E. & A. R. Jour. C. M. I., Vol. XII, p. 141, 1909.

The Mineral Resources of Newfoundland; Howley, J. T., Jour. Vol. XII p. 151, 1909.

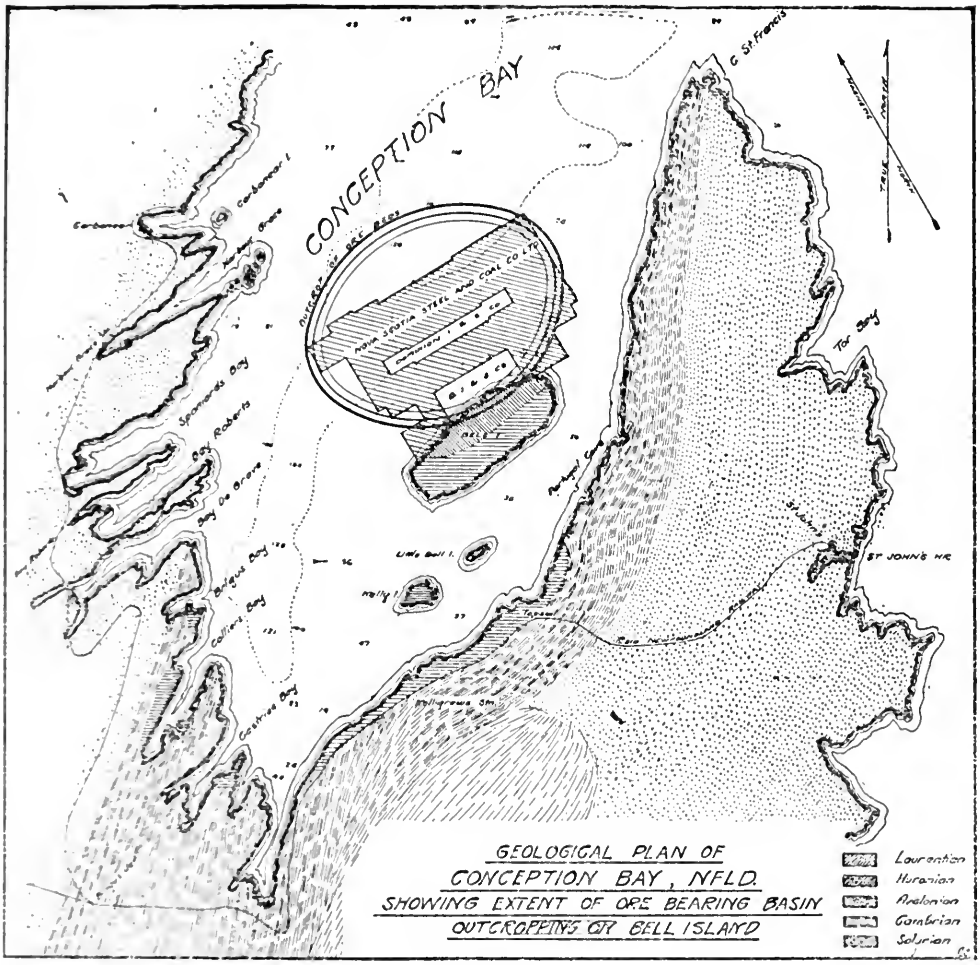


FIG. I.

feet and four feet in thickness respectively; while the third, marked No. 6 the "Scotia," averages seven feet. In the submarine areas, there is a substantial increase in thickness in all three beds.

These beds occur in the form of a closed synclinal trough, the southern edges of which interpenetrate with the Island and where out-cropping form the segment of an ellipse. (See Fig. 1). The ore beds pass beneath the waters of the bay, but do not reach the land on the other side.

Judging from the normal inclination of the various portions of the series where visible, the opposite outcrop of the lowest band would re-appear at the surface about five miles from the north side of the Bay; while the centre of the basin must be in the bay three or four miles to the north of the Island. (For Geological section, see Fig. 3).

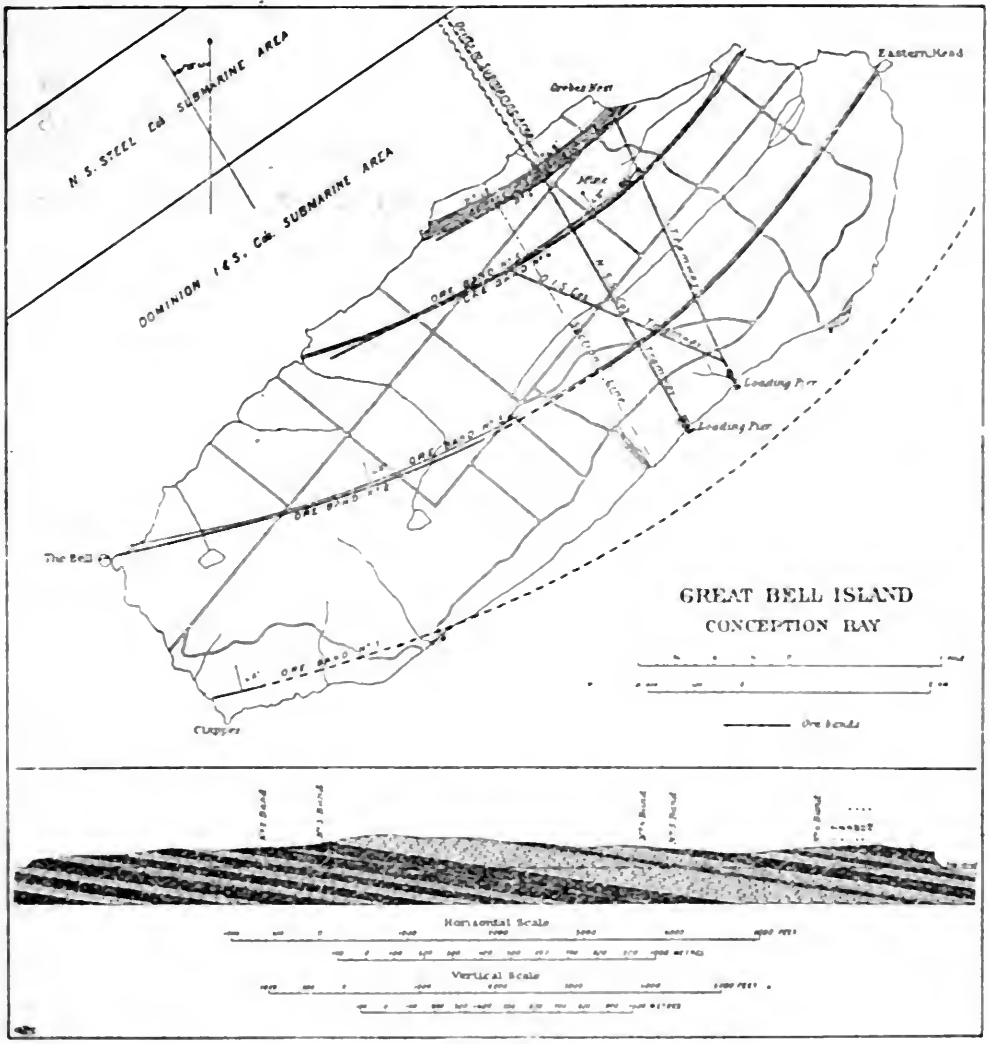


FIG. II.

Map showing iron ore beds occurring on Great Belt Island. Prepared by James P. Howley, F.G.S., Director, Newfoundland Geological Survey.

Faults.—The measures on the north side of Bell Island show a number of faults which have been encountered underground. They are nearly all downthrows and of small displacement, not exceeding twenty-five feet except in one instance, while the others are much less.

The faults occur in two series roughly at right angles to one another, and cross the No. 2 slope, driven on the dip, diagonally. They occurred after the ore had been deposited and were probably caused by intense lateral pressure.

The ore.—The mineral, which has a bright metallic lustre, is a dense red hematite of 4.1 specific gravity. The ore is non-bessemer. The average metallic iron contents of the output from the "Scotia" bed is 53% to 56%, with 7% to 9% silica, phosphorus .8 to .9 per cent.; and that of the lower bed on the land 48% to 52% Fe and 10% to 15% silica. 0.70 to 0.85% phosphorus. A typical analysis of Scotia ore is shown in the following table:—

TYPICAL ANALYSIS OF WABANA ORE.

	Natural	Dry	
Moisture	0.66%	0.00%	
Loss on Ignition	4.31	4.32	
Silica	9.4	9.48	
Oxide of Iron, Fe_2O_3	76.43	76.94	Met. Fe 53.86
Alumina. Al_2O_3	3.52	3.55	
Phosphoric Acid, P_2O_5	1.61	1.62	Phos. 0.85%
Oxide of Manganese, MnO_2	0.83	0.84	Mang. 0.65%
Lime, CaO	1.800	1.81	
Oxide of Magnesium, MgO	0.837	0.84	
Sulphuric Acid, SO_3	0.430	0.44	Sulphur 0.018
Vanadium	trace	trace	

Average analysis of 40 cargoes totalling 220,000 tons shipped to Philadelphia during 1910.

Iron	Moist	Phos.
53.71	2.31	.868

The ore posseses a remarkable natural rhombohedral cleavage, probably caused by the pressure which formed the faults. The ore from the surface mines breaks into parallelopipeda of comparatively uniform size, the blocks being seldom larger than 8 inches square or smaller than one and one-half inches square.

The ore from the underground workings does not display so marked a cleavage, which characteristic seems to decrease as depth is attained.

AVAILABLE ORE.

Mr. James P. Howley, F.G.S., director of the Newfoundland Geological Survey, in a recent paper read before the Geological Congress held in Stockholm, estimates the ore in the Wabana basin as follows:—

"I have made an approximate estimate of the probable amount of ore this trough may yet contain, taking into consideration all the beds over one foot in thickness. By the aid of the dips and strike of the strata, where accessible, it is possible to form a fair idea of the extent of the trough, and unless some unforeseen disturbance takes place, whereby the ore may be greatly diminished or thrown out altogether; and provided the bands maintain their thickness and stratified character, throughout, the result arrived at reaches the enormous total of 3,635,000,000 tons."

Mr. H. Kilburn Scott, M.I.M.M., of London, reported on the available mineral in the Scotia property early in 1909, as follows:—

"It has been shown that the Wabana deposit is exceptionally regular, both in thickness and quality of ore, this over several miles of outcrop and underground workings as well as in the slope for a mile in the submarine area. Moreover, while the area of the Ore Basin is a matter of conjecture, the regularity of the dip of the beds is such that it must be of a width so great as not to disturb any conservative estimate of ore reserves. Small faults have been encountered from time to time in the slope of the submarine areas, but this is no reason to anticipate any great dislocation of strata sufficient to cut out any of the beds, as the cover is gradually increasing and already measures 450 feet. Thus while strictly speaking the amount of ore in the Nova Scotia Company's area absolutely proved by the submarine slope is small, the present face being only 500 feet past the Dominion Steel Company's limits, yet so many important factors necessary are known that it is possible to make a reasonably safe estimate of the ore available for extraction.

"I therefore propose to take as mineral practically guaranteed that of the land area equal to 2,000,000 tons and also the mineral in the area between the outside of the Dominion submarine areas adjoining the island and a parallel line through a point one-third of the length of the Nova Scotia Slope measured from its present face, the figure being closed by the submarine outcrop.

"As mineral reasonably supposed to exist I take that found in the area between the limit of the mineral practically proved and the outside area of the Dominion Company closing the figure as before by the submarine outcrop.

"The contents of the remaining outside area, characterized as mineral which may exist not so much owing to its existence being less certain than in the other areas, but because its development must be deferred for such a long period owing to the large reserve of ore practically proved."

And gives the gross tonnages:—

Mineral practically proved...........	204,000,000 tons
Mineral reasonably supposed to exist..	448,500,000 tons
Total	652,500,000 tons

Then deducting the mineral lost in pillars and by faults and poor zones; arrived at the total recoverable ore as—

Mineral practically proved...........	104,000,000 tons
Mineral reasonably supposed to exist. .	291,525,000 tons
Total......................	395,525,000 tons

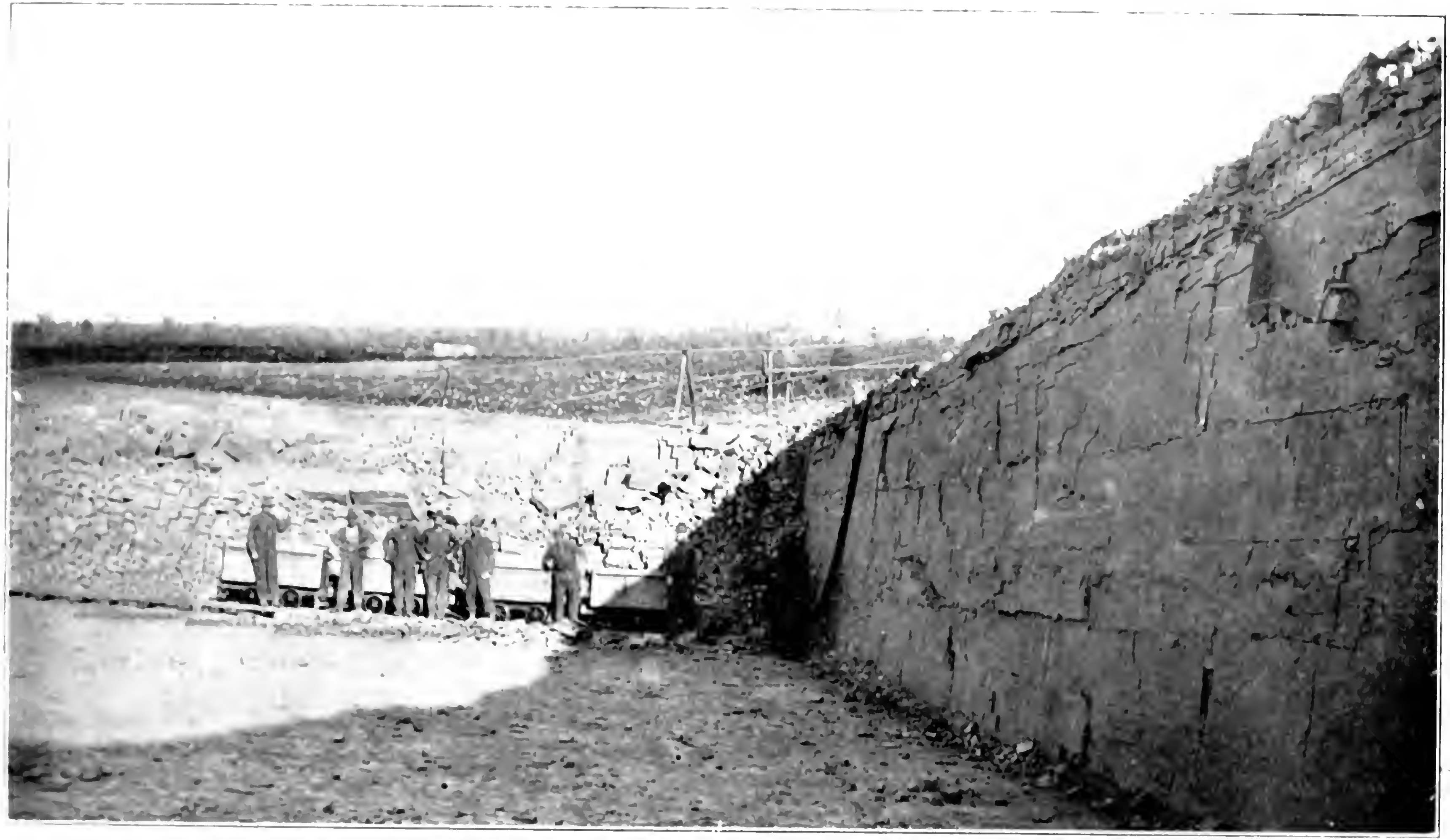
Since this report was written, the submarine slope has advanced a further distance of half a mile seaward without meeting adverse conditions.

THE MINES.

From 1894 to 1899, the Company operated the lower bed by open-cut mining.

At the latter date, mining employing similar methods was commenced upon the Scotia bed, and in 1902 slopes were driven to develop the land areas. Surface and underground mining was carried on simultaneously, as it is to-day, although the larger tonnage is now derived from underground.

Two mines, known as No. 1 and No. 2, are now operated on the land areas and are mined by the room and pillar system. These slopes were driven on the dip half a mile apart, the main levels being broken off simultaneously on both sides at 250-foot intervals and driven nearly at right angles to the dip but sufficiently against it to give a grade in favour of the load toward the hoisting slope.



Open Cut Mining at Wabana in the Lower Bed.

Cable-operated Tramway from Pier to Mine, at Wabana Iron Mines.

Open Cut Ore Face, showing Characteristic Rhombohedral Cleavage, at Wabana Iron Mines.

At various distances in the levels, headings are driven against the dip and off these rooms are broken, parallel to the level and opposite one another. The rooms are spaced at 35 feet centres and thus are 15 feet wide, separated by 20-foot pillars. Every forty feet the pillar is broken through from the lower side.

Drilling:—The drills employed are Sullivan U.D. 3 inch and are worked by a crew of two men, one driller and a helper.

Labour conditions on the Island, while good on the whole, yet suffer from the fact that the working-population is almost constantly on the move. This is due largely to the circumstance that for generations the fisheries have given employment to the the Newfoundlander, and a relatively small class has as yet forsaken this vocation to engage in mining. It is thus difficult to secure the steady service of efficient drillers.

To overcome this difficulty a "drill boss," was appointed whose duty it is to keep constantly on the move from drill to drill, locating the holes to be drilled, the inclinations, etc. The "drill boss" at the end of each day measures the number of feet drilled by each drill-crew, which data he enters upon a report form, giving the date, the number of the working face, the name of the driller and helper, number of hours worked, the number of drill used, and the number of holes drilled. By this method of supervision, tolerable efficiency is obtainable from even unskilled labour, and the work of each driller is systematically checked. In the ordinary room face, 15 feet wide by 8 feet high, twelve holes are drilled, the 8 feet steel being employed last. An ordinary driller's day's work (ten hours) represents from 75 feet to 80 feet, while the best machine-man accomplishes from 85 or 90 feet.

Each drill is numbered and when sent for repair is tested by means of a pneumatic tester invented by the Company's Engineer, A. R. Chambers, M.E.

After refitting, it is again tested and the data in respect of the increase in efficiency, as well as the nature of the repairs and their cost, are recorded in a Drill Book, which thus contains the complete history of each drill from the time it was put in use.

The sets of drill steel for each drill are also marked with the same number as the drill, and regular notes are made of the steel as it is sent to the surface each day for the sharpening. This enables a record to be kept on the steel used by the respective drillers.

A pneumatic drill sharpener is employed to sharpen the drill-bits, and no difficulty is experienced in supplying bits for fifty machines.

A bonus system has been in practice for some few years past; details of which may be of interest:—

From the daily reports made up by the "drill boss" the "muck boss" and the blaster (the duties of the two latter officials will be explained more fully later) which give the number of feet drilled, hours worked, dynamite used and tons broken for each working face, the driller's efficiency is calculated as follows:— A nominal value is placed on the ore, at the rate (say) of $1.40 per car, and put to the driller's credit. On the debit side of the account is placed the value of the labour, dynamite, and drill-repairs incurred in gaining this ore. The amount remaining to the driller's credit is called his efficiency and if above the mininum bonus efficiency, falls into one of three classes: 1, 2 and 3. Those entitled to be included in the respective classes receive a bonus of twenty, thirty, and forty cents per day of ten hours during which that standard of efficiency was maintained.

The system tends to make the driller more careful; for in order to attain to a high efficiency standard, he must place his holes to good advantage, take care of his drill, and drill a large number of feet per day.

An average output of forty-four tons of ore per drill per day is expected.

Blasting.—One of the most difficult problems to face under present conditions at Wabana, where a high daily tonnage is being won within a relatively small underground area, is that of blasting.

The working faces are so close to one another, that it is impossible to blast during the day, and the resulting dynamite fumes would be another drawback to economical working. All the blasting is consequently done at night.

The ground is tight and the employment of a heavy explosive is therefore necessary. The explosive used is Acadia 50%—1¼ inch dynamite, the detonators being Nobels No. 7 low-tension detonators, which are exploded by means of a Nobels 50-hole shot-firing battery. The average face of twelve holes when charged carries from forty-one to forty-four lbs. of dynamite. Thus about half a ton of dynamite is daily consumed underground. Much careful thought has been devoted to working out a good blasting system, and the method now in force has proved highly effective.

All blasting operations are directly in charge of a blasting inspector whose duty it is to examine daily all the battery circuits, to see that the battery stations are safe, investigate all misfires and misholes, examine the magazine and, generally superintend this department.

The actual blasting in each mine is done by two men and two helpers, one crew for each section east and west. These men must pass an examination before being appointed as blasters and must have made a thorough study of the Company's blasting rules and regulations.

Each evening after the cessation of work in the mine, the blaster and helper carry the dynamite, detonators and firing battery underground, and immediately proceed to fire the places, a list of which has been given to the blaster by the "drill boss."

The blasting circuit from the face of each room to the firing or battery station is permanent, being made of No. 14 B. & S. covered wire, which is added to as necessary from day to day by the blasting circuit wiremen, whose duty it is to test each line with a pocket galvanometer, and to label the battery station end of the line with a wooden tag bearing the number of the face and the last date when tested.

Before charging the holes, the leading wires at the face end are connected in series with a detonator and a resistance coil equivalent to fifteen to twenty detonators, the firing battery connected and the single detonator fired. If this is done satisfactorily, it proves the line and battery to be in good condition.

The holes are then loaded, No. 22 B. & S. covered leading wire being used to connect with the permanent line, and the detonator wires connected up as usual. Then before connection is made with the firing battery the circuit is tested with a hand galvanometer and in all cases must answer successfully to this test previous to firing.

The blaster fills out a report form for each shift. The report shows the number of pounds of dynamite and detonators taken into the mine, the number of misholes or misfires; the number of each face found, number of holes fired, and plugs burned at each face.

The firing batteries are tested weekly by the electrician and tagged accordingly.

Before leaving the detonator store room the detonators are all tested by galvanometer. By this system of close checking and supervision, the number of misfires and misholes have been reduced to a very low figure.

Shovelling.—Shovelling is done by men in pairs, one pair at each working face or room that has been drilled on the previous shift. All the shovellers in one section of the mine are in charge of a "muck boss" whose duty includes that of seeing that all the ore is cleaned up at each face for the day and who fills out a report form to the underground manager, giving each shoveller's name, number of hours worked, and number of cars loaded.

The mine floor is smooth and makes a good shovelling surface. The men shovel directly into steel cars holding 1.65 tons of ore, and which when loaded they push out to the headway track. The average man loads sixteen tons per ten-hour day.

The shovellers' bonus system is as follows:—For the day's pay it is expected that each shoveller shall load nine cars or 14½ tons. For each car above this number, he is given as a bonus an amount equivalent to the cost of loading it, based at ten cents per ton. For example, if a shoveller loads seventeen tons or three tons per day above the minimum requirement, he receives thirty cents extra pay.

This bonus system has increased the efficiency of the shovellers and has also resulted in reducing the total cost, since a larger output is handled with the same fixed charges and staff. By this system, moreover, the work done each day by the individual shovellers is brought directly to the attention of the foreman and underground manager, and, furthermore, the men have the assurance that they will be paid for extra exertion.

Underground Haulage.—For all underground haulage at present compressed air double-cylinder haulage engines are employed, the system being main and tail ropes or plane haulage. The latter is, of course, the simpler and more efficient method and is utilized whenever practicable. The roads are so laid out that a grade of at least 2 per cent, is always in favour of the load. Eighteen lb. rails are in use throughout the workings except upon the main slope and levels where a twenty-four lb. tail is utilized.

The loaded cars are pushed, by the shoveller, from the working face to the headway, from which point they are lowered by the headway haulage engine, and allowed to run back upon the level, where they are left standing. The headway rope is then coupled to the empty cars standing upon the level siding, which are hauled up the headway, and delivered to the siding of the working rooms, as required.

After a sufficient number of loaded cars, to make up a trip, have accumulated upon the level, the trip passes out to the hoisting slope controlled by the level engine rope. This rope is next coupled to a trip of empty cars which it pulls in to the headway siding. The loaded trips are hoisted to the deckhead in the usual manner.

Timber.—The quantity of timber used in the mine is small and could, if it were not necessary to carry the compressed air pipe line and blasting wire to the faces, be dispensed with almost entirely; except, when, of course, the pillars are being removed. Indeed, the roof is one of the features of the mine, a fact that will be better appreciated when it is stated that 85% of the ore is commonly removed without timbering. In many places the writer has seen an area of 100 feet square entirely unsupported.

Timbering is restricted to the main levels and slopes, except on occasions when required to support an unsafe section of roof.

The timber is supplied from the Company's timber property of 50,000 acres, at Gander Bay, about two hundred miles to the north, where it is cut in winter and forwarded by steamer to Wabana in the summer months.

Telephones.—Telephones are installed in all the principal places in the mines and upon the surface, thus affording communication between all departments. This greatly facilitates operation, and is especially advantageous in the ordering of supplies. Thus the mine foreman calls up the mine office and asks for the required material; an order for the supplies is then sent to the Central Store after being signed by the Underground Manager, without whose order no material for the mines is given out. The supplies are then at once carried by a store messenger to the place desired. Hence a saving in time and money is effected, since a store messenger is paid a lower wage than the lowest paid underground labourer.

A daily record and itemized cost of the supplies delivered to each mining department on the preceding day, is forwarded by the Storekeeper to the Underground Manager, who thus, having a daily check upon all the mining supplies used, is in a position to at once detect waste and to avoid or prevent extravagance.

Surface Mining.—The ore mined from the surface requires to be stripped of its cover, a steam shovel being employed for this purpose, working over the ore to the dip, until 20 to 25 feet of cover is removed. The uncovered ore is mined by open cut methods or quarried and hand picked when loaded. This done, the cars are hauled to the main tramway.

Curve Analysis.—A striking instance of the uniformity in composition of the ore is afforded by the use of what is called the "Analysis Curve."

The iron-content of the pure ore of each mine is very constant as also is the iron-content of the parting rock, which at some places is 6 inches to 8 inches in thickness and at others does not appear at all.

Measurements are made daily of this rock in all the working faces and the results entered in a report. From these, by the aid of a curve, the mine clerk rapidly derives the analysis of the ore at each face, and the average analysis for the mine. After deducting the rock removed at the picking belt, the average analysis for the ore shipped is obtainable.

These analyses are incorporated in the daily reports to the manager, and have been proved to be accurate, within one-tenth of 1%.

The curve analysis for a whole season's shipments has checked to within this figure with the buyers' analysis.

The System.—From what has been said, it is apparent that the mining has been very thoroughly systematized. Specialization has been rigorously adopted and separate reports are made for every branch of the work and these checked daily by the underground manager. The figures are then incorporated in summarised reports, giving such data as enables the mining efficiency to be ascertained day by day.

For example, the Underground Manager knows each day the tonnage of ore mined both underground and surface per lb. of dynamite; the output per man per day, etc. The latter figure, the ore mined per man per day, is maintained at 4.0 tons, for weeks at a time. And in calculating this figure all those employed in mining, preparing and delivering to the tramway, underground upon the surface, and round and about the deckhead, are included.

It need hardly be said that this method has proved advantageous. A standard thereby is established for each class of work, below which no man can fall with impunity. Furthermore, it not only is selective by indicating the best workmen, but encourages men who are capable of doing good work, since they realize that their capabilities are known and will be rewarded accordingly. This system has been evolved by the Company's very efficient and painstaking chief ore and quarries engineer, R. E. Chambers, M.E.

Deckhead.—Upon the deckhead, the cars are dumped one by one in a tipple of the ordinary type, the ore passing over a grizzly and into a No. 7 Gates gyratory crusher, delivering to a 36 inch rubber picking belt inclined at a 30% grade. The ore is finally delivered into a storage bin and loaded into tramline cars which carry it to the pier.

STOCKPILING.

In winter, since navigation is usually closed from January to April, the ore is mechanically stockpiled.

This is done by means of a side-dump car propelled by a main and tail rope driven by a single drum engine. The steel rope is led from the engine, placed a short distance to one side of the feeding chute, to a sheave wheel some three or four hundred feet distant, thence across a second sheave wheel to the line on which it is desired to pile the ore, and down this line to the car at the chute. From the other end of the car the rope passes around a sheave wheel back to the engine. This car is of the ordinary side dump type, possessing the necessary mechanism to open the doors when engaging a rail set in the track.

The car runs on a track at an inclination of about twenty degrees, and is kept ahead of the pile a couple of car lengths by means of a wooden frame, the weight of the lower end of which is sufficient to keep the loaded car from upsetting.

The cycle of operation now is as follows:—The car, upon being loaded is hauled to the top of the pile and, engaging the set, discharges over the end of the pile. The engine is then reversed and the can run back to the loading chute for another load. The resulting pile is in the form of a triangular pyramid and can be built up to any size depending upon the area to be covered.

The only labour necessary, excepting that of an engine driver, is when it is required, from time to time to move the wooden frame ahead, and even then the heavy work is performed by the engine. By this means the ore is readily handled as fast as it comes from the mines, up to 1,500 tons per day, at the cost of under 1 cent per ton.

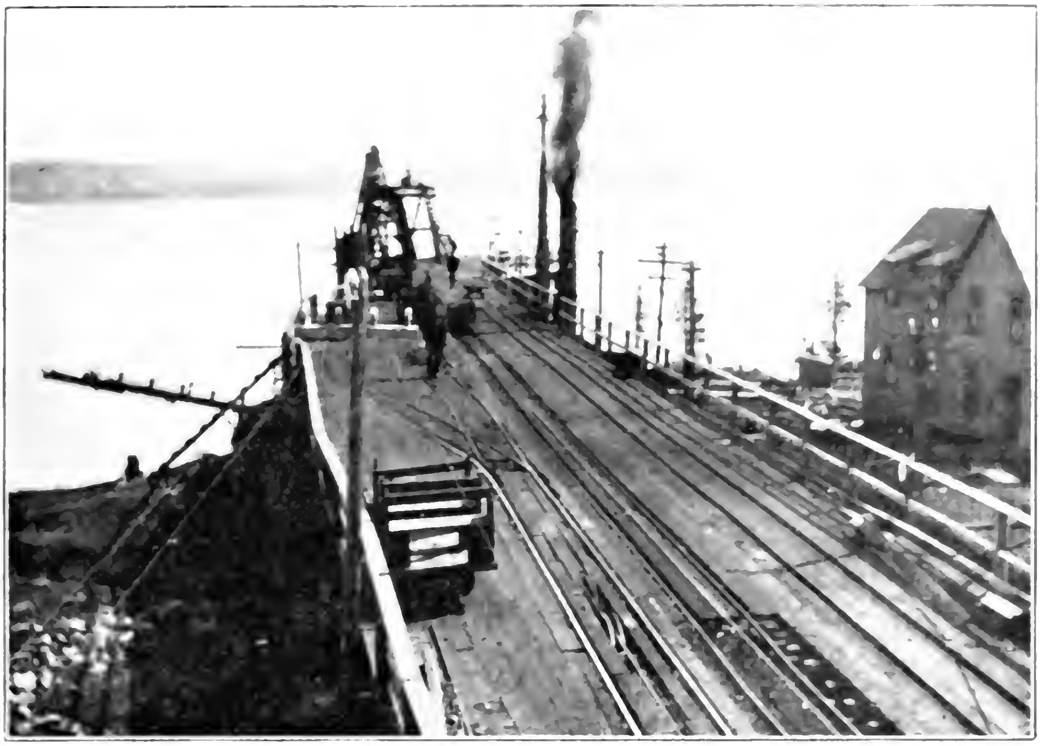
The ore stockpiled in the winter is picked up in the busiest part of the shipping season and sent over the tramway to the pier in the usual fashion.

The rehandling of this portion of ore may be done by steam shovel or, as is the current practice with the Scotia Company, by means of a scrape or drag bucket, controlled by a wire rope passing through a sheave pulley which runs back and forth upon a suspended steel cable, one end of which is fastened upon the top of a wooden tower.

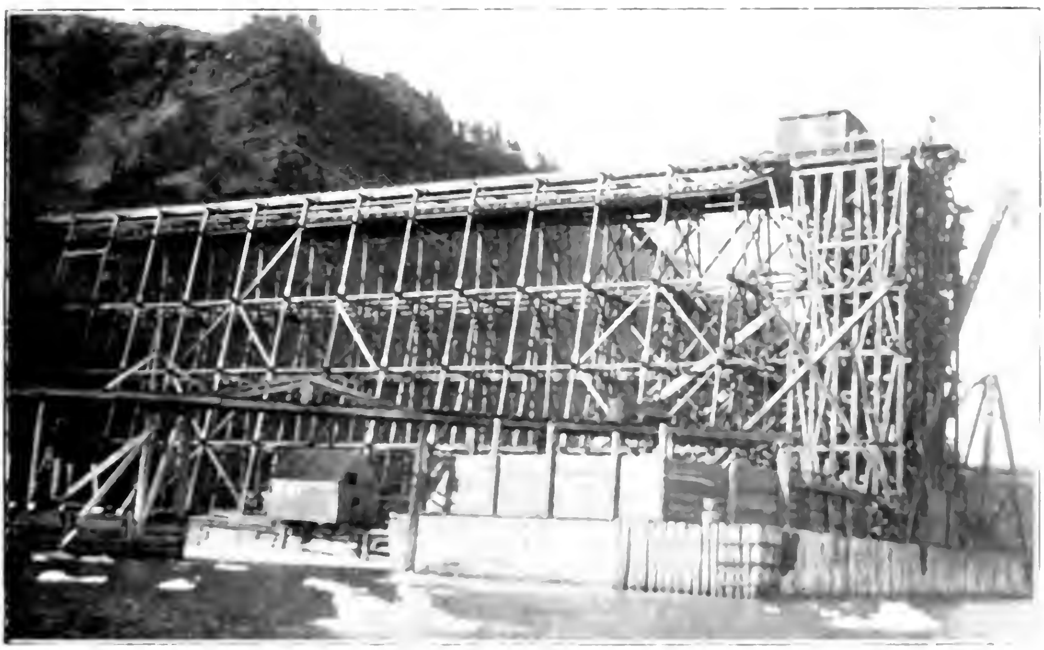
This tower contains a bin of thirty to forty tons capacity, and the necessary chutes, etc., and is supported upon wheels, thus enabling the bucket to be operated along all the radii of the circle covered by the stockpile.

The drag bucket is equipped with a tripable bottom door, opened by a curved tail striking against a plate situated in the tower frame, immediately above the bin. The bucket is operated by a double-drum duplex hoisting engine of the ordinary type.

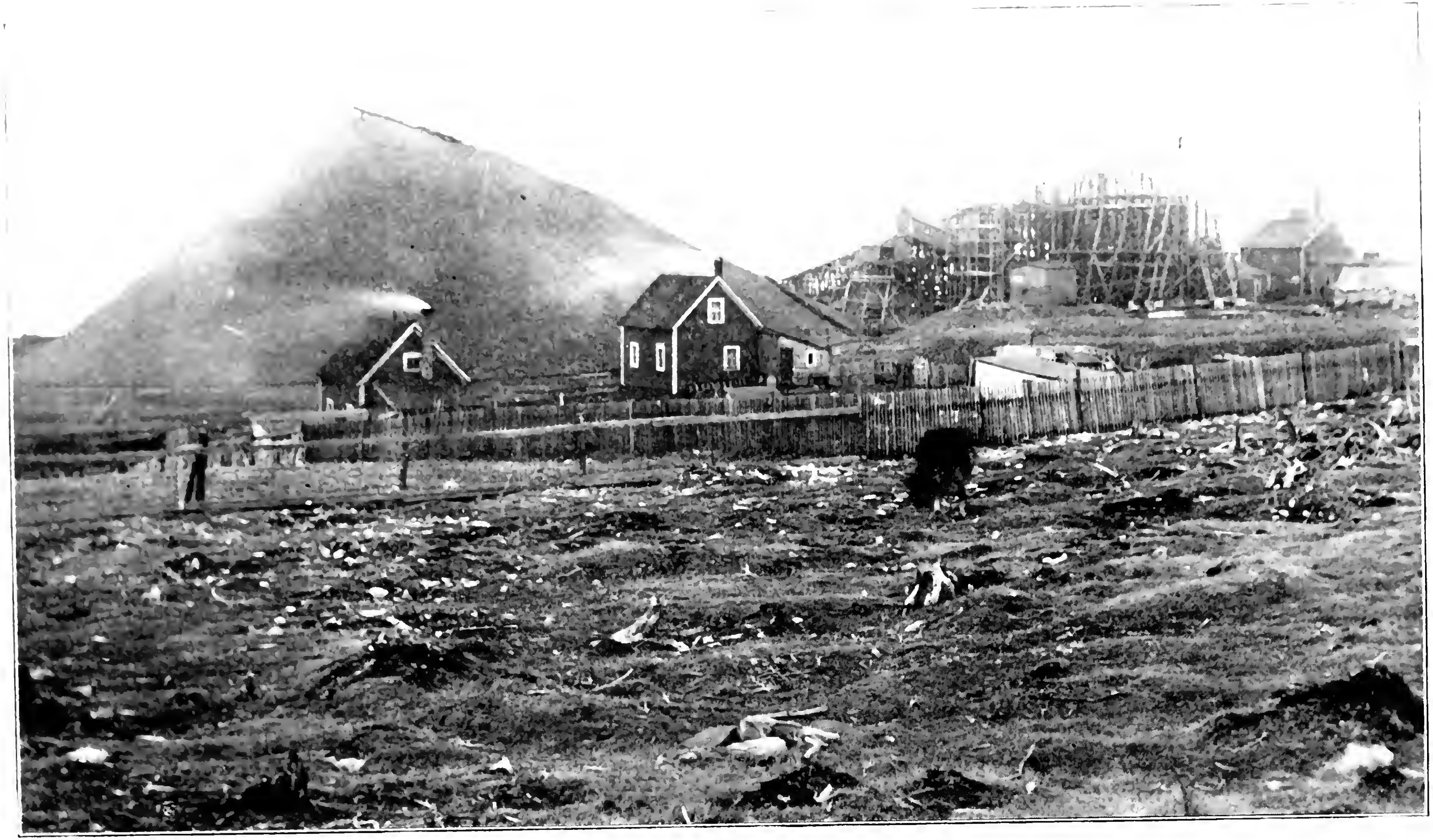
The cycle is now as follows:—The bucket is lowered to the ground at the foot of the inclined pile of ore and its latch closed. A combined hoisting and forward motion is then imparted to the bucket, its nose thus constantly kept against the pile until loaded. The engine is then reversed and the loaded bucket rapidly conveyed upon the suspended wire back to the tower, when it is automatically dumped immediately over the bins in the manner already mentioned. This accomplished, the bucket is rapidly lowered and the cycle again commenced.



Trestle and Tipple over Storage Bin, at Wabana Iron Mines



Side View of Shipping Pier, at Wabana Iron Mine



General View of Surface No. 2 Mine, Wabana, showing Stock Pile.

With this simple apparatus, 1,000 tons per day of ten hours can readily be handled. And although it might perhaps be undertaken more cheaply with steam shovels, yet the apparatus described has the advantage that its initial cost is only a fraction of that of the former, a consideration, especially as it is in operation not more than 30% of the time.

SURFACE HAULAGE SYSTEM.

To transport the ore from the mines to the shipping pier situated on the south side of the island, slightly more than two miles distant, a double-track tramway, operated by an endless cable, is employed. The tramway is in the form of the letter "T," the head of which lies parallel and close to the outcrop of the Scotia bed and tapping the various surface pits and the mines, No. 1 to the west and No. 2 to the east of the long leg which stretches in a straight line in a southerly direction across the island to the shipping pier.

The tramway is of 2-foot gauge and has two tracks, one for loaded cars and the other for empties. Twenty-eight and eighteen pound steel rails are used on the respective tracks.

At the point located midway between the mines, where the tramway separates in three directions, and locally called the "bottom," the grades are so arranged that by ungripping the cars, they move by gravity each in the required direction; the loaded outgoing cars falling from the east and west "full" tracks into the pier or main full track, and the empties returning from the pier toward their respective empty track on either the east or west branch for distribution to the mines.

The cable is a 1 inch diameter Lang Lay plough steel, and is supported upon wooden rollers at short intervals, and by Hadfield cast manganese steel wheels at the crest of each rise. The cable is slightly over seven miles long, and its tension is uniformly maintained by means of balance weights, placed near the haulage engine at the pier, and at the east and west extremities of the tramway.

The tramway is operated by a compound condensing steam engine, of 125 horse power, geared down to a driving bull-wheel to give a cable speed of 350 feet per minute. Its site is alongside the pier.

The cars, built of steel, have an average capacity of 1.8 tons of ore, as loaded from the chute, and are of thirty cubic feet capacity; and are attached to the cable by means of grips, consisting of a series of levers readily operated by a plain wrench with a 30 inch handle. Two of the grips, one at each end, hold the car securely to the cable upon the steepest grade on the line and may be used upon a grade up to 10%.

It is necessary to ungrip and regrip the cars, when they pass the "bottom" in either direction, as well as at the beginning and end of the journey. This is done by "grippers," eight men being employed for the purpose, who besides a few "spraggers" include the only labour required for the operation of the tramway. Under existing conditions, the actual capacity of the line, allowing for all stops, is 3,000 tons per day. Indeed, frequently by working overtime, the daily tonnage sent over the line has been maintained at 3,500 tons per day for weeks at a time.

Trestle and Bin at south side of Island.—The ore cars upon arriving at the south side of the Island, run directly upon a trestle which at its outer end has a height of 35 feet.

The cliff at this point is 200 feet high and immediately to the east is the storage pocket. In building this pocket, advantage was taken of a small ravine, which was enlarged and the mouth closed with crib work until it resembled a rectangular hopper, the bottom terminating in a chute. This chute delivers the ore upon a bucket conveyor placed in a horizontal tunnel driven into the cliff.

This pocket has a capacity of 25,000 tons of ore. Under normal conditions, the ore is dumped from the cars in passing through a tipple directly into the storage bin, but when the latter is nearly full, on to a rubber belt conveyor which piles the ore, thus increasing its capacity to 30,000 tons.

The single tipple has a capacity of five cars per minute or, say, 9 tons of ore.

Shipping Pier.—The tunnel above mentioned, in which the conveyor moves is 75 feet above high-water and the shipping pier is built in line with it and with its top at the same elevation. Thus the ore is carried from the storage bin on the conveyor along the top of the shipping pier to dump into a small bin situated just above the loading chute. This bin has a capacity of 200 tons of ore and is necessary in order to hold such ore as may be delivered by the conveyor after the signal to stop the conveyor engine is given.

The conveyor is of the steel link chain type, built with links 3 feet 9 inches apart and 37 inches long, pinned together by axles upon the outer end of which wide faced wheels are located. These run upon a full track of 24 pound rails, along the top and return on the empty track of 18 pound rails underneath. The space between the conveyor links or frame is filled by "U" shaped steel buckets, which actually carry the ore. The buckets, wider on top than the length of the links, are nosed on one end and thus each engages upon the next bucket, so that the load is distributed over the whole axle; and are further held in place by angle clips rivetted on either side so as to engage against the link bars and prevent the bucket falling out when upside down on its return.

This conveyor travels around large cast iron sprocket wheels, one at each end, at 412 foot centers, the outside wheel doing the driving and driven by a 20 horse power duplex haulage engine, directly geared to give the necessary speed.

Each bucket carries 1,500 pounds of ore and the conveyor travels at 200 feet per minute, thus having a capacity of 3,000 tons per hour.

The pier itself is constructed of Georgia pine built upon a pile-driven and ballasted crib. The trestle which connects the pier with the cliff at the end of the storage pocket tunnel is built of native timber.

The trestle bents are spaced 15 feet centers; 8 x 8 timber being used throughout except at the pier head, where the structure of Georgia pine is much heavier and strongly braced.

All loading is done from a single pivotted chute, which is balanced, the horizontal and vertical movement being controlled by wire guy ropes operated by drum engines from the pier head as also is the trimmer on the end of the main chute, which deflects the ore to the desired position in the ship's hold. This apparatus trims the ore admirably, and no hand-stowing is ever required in the trunk steamers employed in the trade.

Wabana loading records, as far as known to the writer, have, loading from a single chute, never been equalled.

During the season of 1909, between April 19th and December

23rd, the output represented 459,523 tons of ore, which were loaded on vessels in 308 "loading hours" and 50 minutes. This calculation also includes the time spent in moving the vessels. In round figures, therefore, the ore was loaded in ships' holds at the average rate of 1,487 tons per hour; while on occasions this record was considerable exceeded. Thus in one instance 6,676 tons was loaded in 3 hours, or at the rate of rather over 2,225 tons per hour, in another 7,000 tons in 3½ hours, and so on.

SUBMARINE DEVELOPMENT.

Heretofore, attention has been confined to a description of the mine, plant, and practice, as at present in use. It is now purposed to refer briefly to proposed developments and to equipment installed during 1910 with a view to turning the submarine areas to productive account within the present year.

In order to obtain the necessary production cost when mining the great body of ore opened up in the submarine areas, a large daily output is essential. It was consequently decided to install equipment necessary to maintain an output of at least two thousand tons per day of ten hours.

Mining in the Scotia submarine areas presents few difficulties other than those incidental to the increased depth and distance from the surface; and these economic drawbacks, while they are not to be entirely overcome, may be materially lessened by a judicious choice of equipment and skilful operation.

Perhaps the most difficult problem to be solved was that of haulage, the minimum haul being one mile.

The underground practice, it has been decided to adopt, includes a system of electric locomotive haulage on the main levels, and the employment of side or bottom dump cars to empty directly into large storage bins excavated immediately over the hoisting slope. These bins, of which there will be one for each level, are sufficiently large to hold at least a day's output from its contributing section of the mine.

Hoisting.—The next stage in the transportation is from the mine pockets to the deck. The safe speed on a slope of this grade was assumed to be not over 2,000 feet per minute, and hence it was found imperative that the load should be a heavy one. As a solution of the problem special steel cars of 45,000 pounds capacity were designed to be operated in balance upon a single drum hoist, so that when one car was loading at the storage bin in the mine the other was emptying upon the deckhead.

As it was required that unloading should be accomplished rapidly, an ordinary tipple was out of the question for emptying the car, hence it was decided to adopt a bottom-dump car. The car is of especially heavy construction, mounted upon standard 3-foot gauge trucks, and equipped with a mechanism that positively operates the opening and closing of the bottom.

The slope track upon which the car runs has an average grade of 16% and is constructed of standard 80-lb. rails, with angle splice bars, the other fastenings, sleepers, etc., being extra heavy; while vertical curves are installed at all changes of grade.

The hoisting engine selected and installed is a first-motion duplex, Corliss valve steam engine, designed and built by Fraser & Chalmers of Erith, England, with cylinders 28″ x 60″ diameter, double drum 11 feet diameter, equipped with steam operated post brake, Whitmore overwind, and safety device, the drums being sufficiently large to hold 10,000 feet of $1\frac{1}{8}$ inch diameter rope. The rope is of $3\frac{1}{2}$ inch, 6-strand 7 wires Lang Lay special improved plough steel. The drums under ordinary working conditions are locked together, but they may be operated singly.

Steam is supplied by a battery of Sterling boilers of 464 horse power and at 160 pound pressure, superheated to 100°.

Deck Head.—The deck head and trestle approach is built of Georgia pine timber. The special feature of the deck head is that the loading floor is inclined at an angle of 22°. The weight of the load is thus always on the haulage cable. The loaded car upon being stopped over the deck head pocket dumps immediately, and when the signal to go forward is received from the loading station in the mine at which the other car has just been loaded, the winding is started and the empty drops back under its own weight.

From the deck head bin, which holds 100 tons, the ore may be fed through any one or combination of three chutes. One chute on either side feeding direct into a No. 7 style K. A.C.B. Gates gyratory crusher of which there are two. The third chute on one of the two remaining sides divides to feed upon two steel conveyors, both of which lie on the same line and run in opposite directions, and finally deliver through a right-angle turn chute into the crushers mentioned. These picking belts are provided to handle such roof and parting rock as may accompany the ore and have been included in the design in order that the ore may be picked previous to crushing. On a floor immediately beneath these picking belts is a Zimmer conveyor to which the waste rock is delivered through chutes as picked from the belt. The Zimmer in turn delivers through an opening in the deckhead-house wall into a waste rock bin.

The ore from each of the crushers passes on to a separate 48 inch rubber picking belt of the Robins type, along which it travels a distance of 150 feet, inclined at an angle of 17°, and is finally delivered to an ore bin. This second, or after crushing picking, is done by boys who throw the waste picked off the belts through holes in the belt house floor upon Zimmers placed on the floor below, and which discharge into a waste bin.

In the ordinary course of working, the ore passes directly into the tramcars and thence to the pier, in the manner already described; but in anticipation of and to tide over a possible stoppage in the tramline, the picking-belt ore bin has been built to give a storage capacity of 375 tons.

Ventilation Fan.—A new ventilation plant is being installed to deliver air through an air shaft situated directly above the slope near the shore. This consists of a sirocco fan, 66 inches diameter by 4 feet wide, driven by a direct-connected 200 horse power motor, giving 80,000 cubic feet of air per minute, at 10 inch water gauge.

Provision is made that a second motor may be connected to the other end of the shaft, to give the additional air and pressure required when the workings become extensive. The fan is so installed as to work either blowing direct or exhausting.

At Pier.—Storage Pocket. In order to cope with the additional tonnage and to permit especially of the handling of two classes of ore, which may be necessary should two beds, say, the lower and Scotia, be operated simultaneously, it was decided to provide a second storage pocket alongside and immediately east of that originally installed. This new pocket has a capacity of 30,000 to 40,000 tons, to serve which a trestle was erected equipped with the necessary tipple, elevators, and retarders, to provide for its operation in conjunction with the present tramline. To handle the ore from this new storage pocket a new steel pier having an inclined conveyor and complete equipment is being erected 50 feet east of the present pier. By this arrangement the management expect to be able to still further reduce the present remarkable short loading time, and hope to load their new steamers, each of 12,500 tons deadweight, within three hours from the time of docking, or at the rate of 4,000 tons per hour, or (say) 66 tons per minute.

Power.—This increase of equipment necessarily demanded additional power. After due consideration, it was decided that electricity should be employed for all possible purposes, and such being the case, the proper location for the power station was at the pier end of the line. It became necessary, therefore, to make large additions to the dock front and a new wharf was built abutting the old pier to the west.

This wharf which was completed a year ago, has a face 260 feet long, and a depth of 160 feet, with 22 feet of water at low tide. Upon this wharf was erected a brick power house containing a plant consisting of two 500 k.w. Brown Boveri generator sets. The alternators are direct connected to Belliss Morcom triple expansion surface condensing engines driving at 300 revolutions per minute, and producing 3-phase 60-cycle, 6,600 volt. electricity. The steam is supplied by two batteries of Sterling boilers of 464 horse power, each working at 200 pound pressure, superheating to 100°. Chain grates and induced draft are in use. The electric power is directly transmitted to the submarine mine levels, there being a sub-station near the deckhead and the mine ventilating plant, which are electrically operated.

In the mine all mechanical power will be electrical, including that required for the operation of the centrifugal mine pumps, small haulage engines and portable compressors probably of the Reavell type; one of which in each section of the mine will supply the compressed air necessary for the rock drills.

Coal Gantry.—To handle economically the coal necessary to operate the plant and to bunker the ore steamers with despatch when coal is required by them, a Mead Morrison one-man control coal gantry with a 1¼ ton grab and having a capacity of 1,000 tons per 10-hour day has been installed upon the new pier. This tower has a circular motion, but when at work discharging a steamer remains stationary, and delivers the coal into a bin incorporated in the substructure of the tower. This coal may be removed partly in cars and the remainder mechanically stockpiled on the dock and within the radius of the gantry boom. This arrangement enables of the gantry to again pick up the coal and deliver it to the power plant boiler bin as required.

SUMMARY.

The Wabana mine is undoubtedly one of the largest deposits of iron ore of proven value at present operated in the world. It consists of several beds occurring in a rock basin of large area, the greater part of which extends under Conception Bay, Nfld., but outcrops upon the north shore of Bell Island.

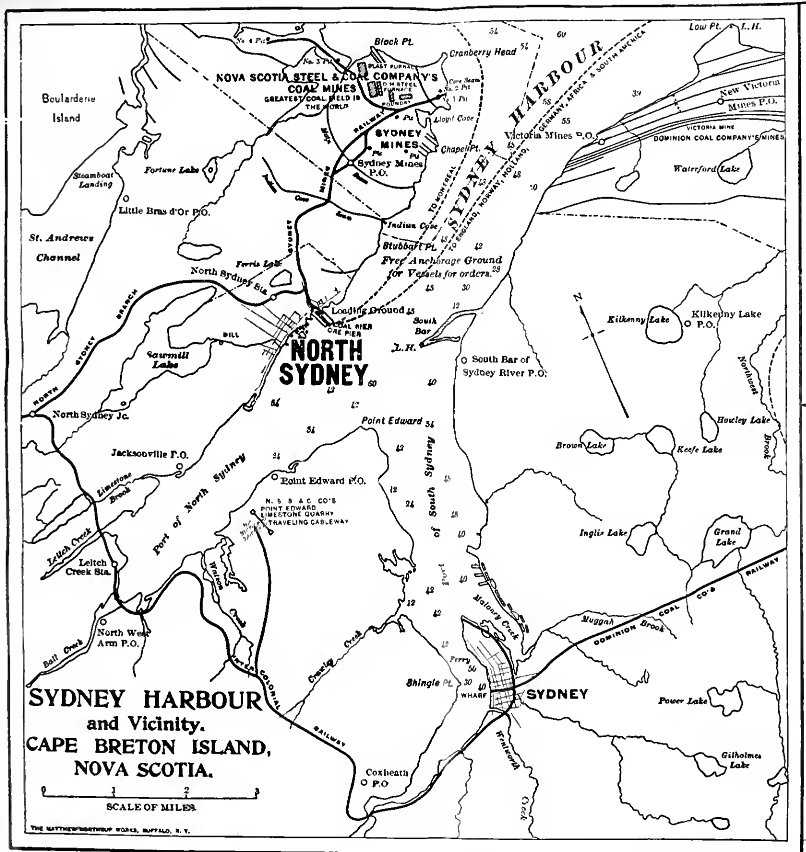
The situation of the deposit on a comparatively small island in the Atlantic Ocean, almost equidistant from Europe and America, affording, therefore a choice of either market, is unique.

From the land areas over 9,000,000 tons have been mined to date, about one-half of which was produced by the Scotia Company.

The company own 33½ square miles of areas in fee simple grant from the Crown, situated within the limits of the iron-bearing basin mentioned. This territory has been developed by means of a slope driven in the Scotia seam nearly 9,000 feet to the deep, and the ore beds have proved to improve in thickness and in iron content. No conditions have been met with adverse to efficient mining.

Sufficient ore has been developed in the submarine territory to assure an annual output of 1,000,000 tons for many years to come.

The Scotia plant at Wabana has all the necessary facilities for efficient mine operation. Further extensive additional equipment of the most modern type is now being installed to provide for an anticipated output of 1,000,000 tons per year from these submarine areas.



Sketch Maps showing situations of respectively Wabana, Newfoundland, the source of the iron supply and North Sydney, where the iron and steel works of the Nova Scotia Steel and Coal Co. are established.

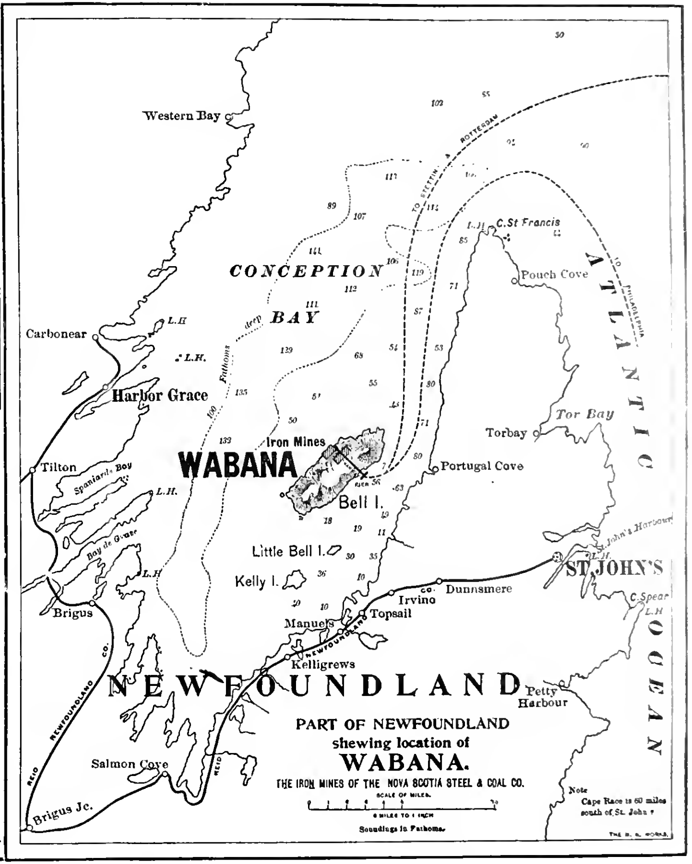
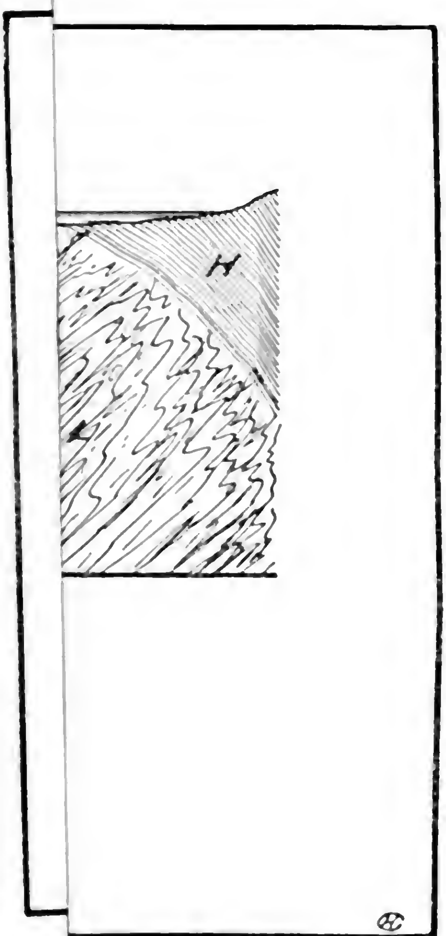
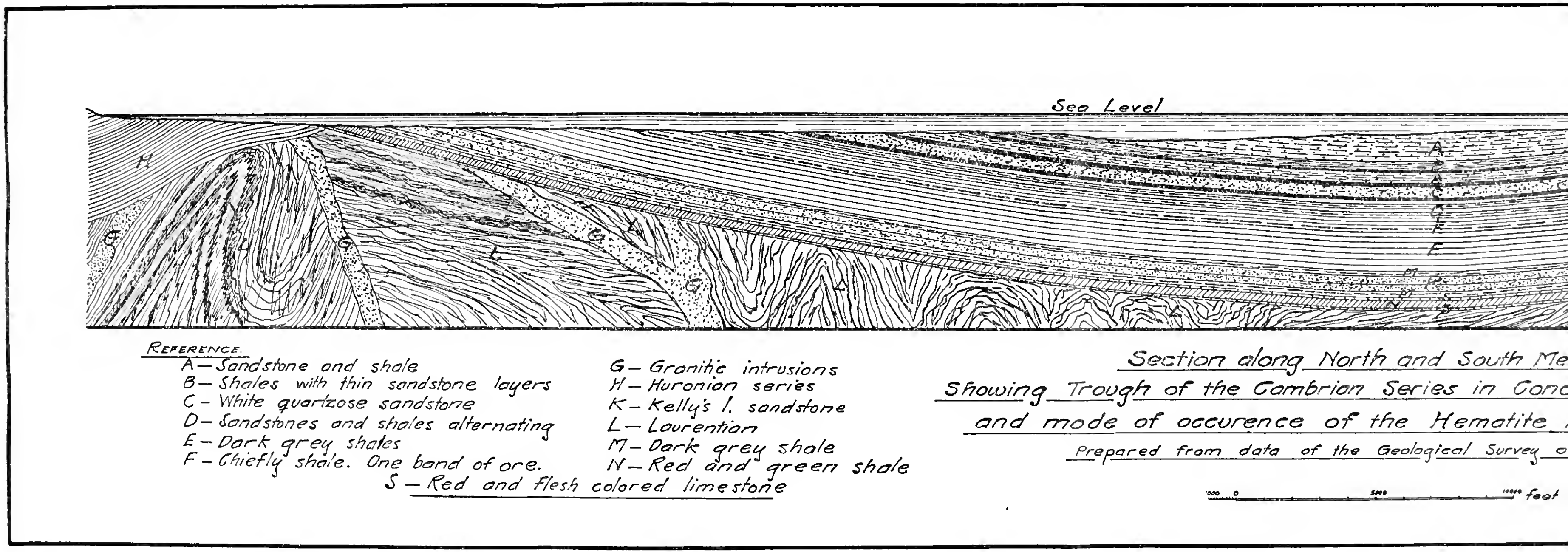


Fig. 5


H



Sea Level
REFERENCE.
A—Sandstone and shale
B—Shales with thin sandstone layers
C—White quartzose sandstone
D—Sandstones and shales alternating
E—Dark grey shales
F—Chiefly shale. One band of ore.
G—Granitic intrusions
H—Huronian series
K—Kelly's I. sandstone
L—Laurentian
M—Dark grey shale
N—Red and green shale
S—Red and flesh colored limestone
Section along North and South
Showing Trough of the Cambrian Series in
and mode of occurence of the
Prepared from data of the Geological
feet

FIG. 3

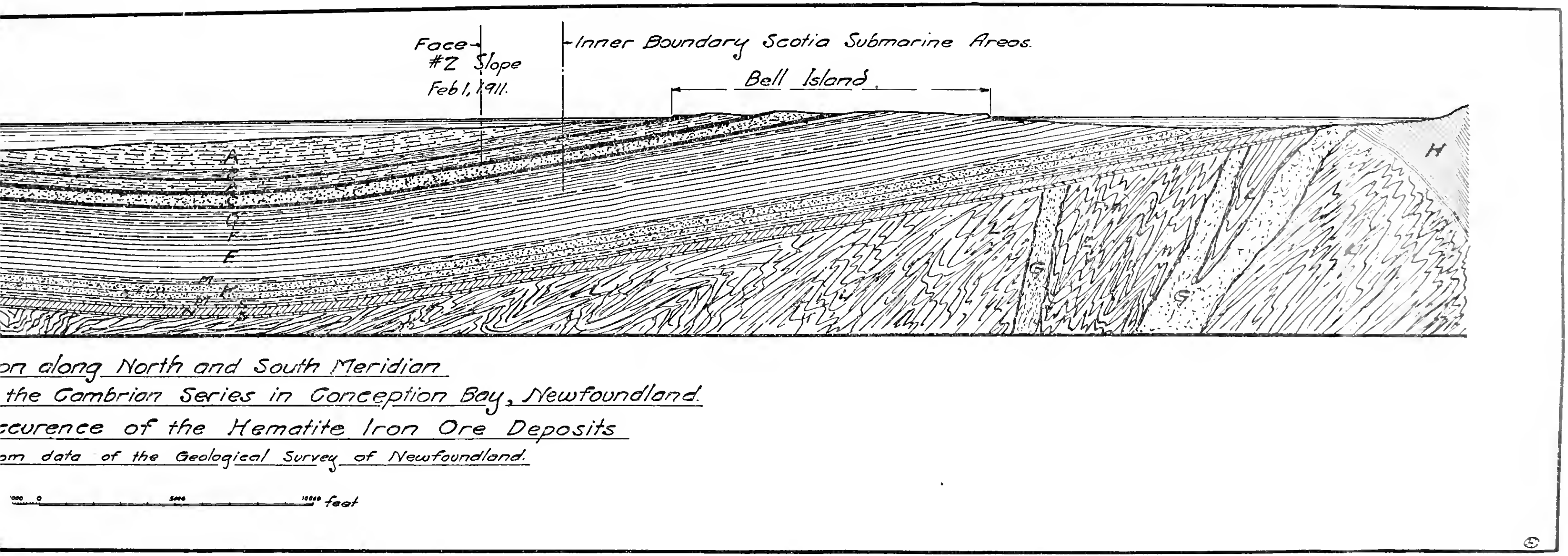
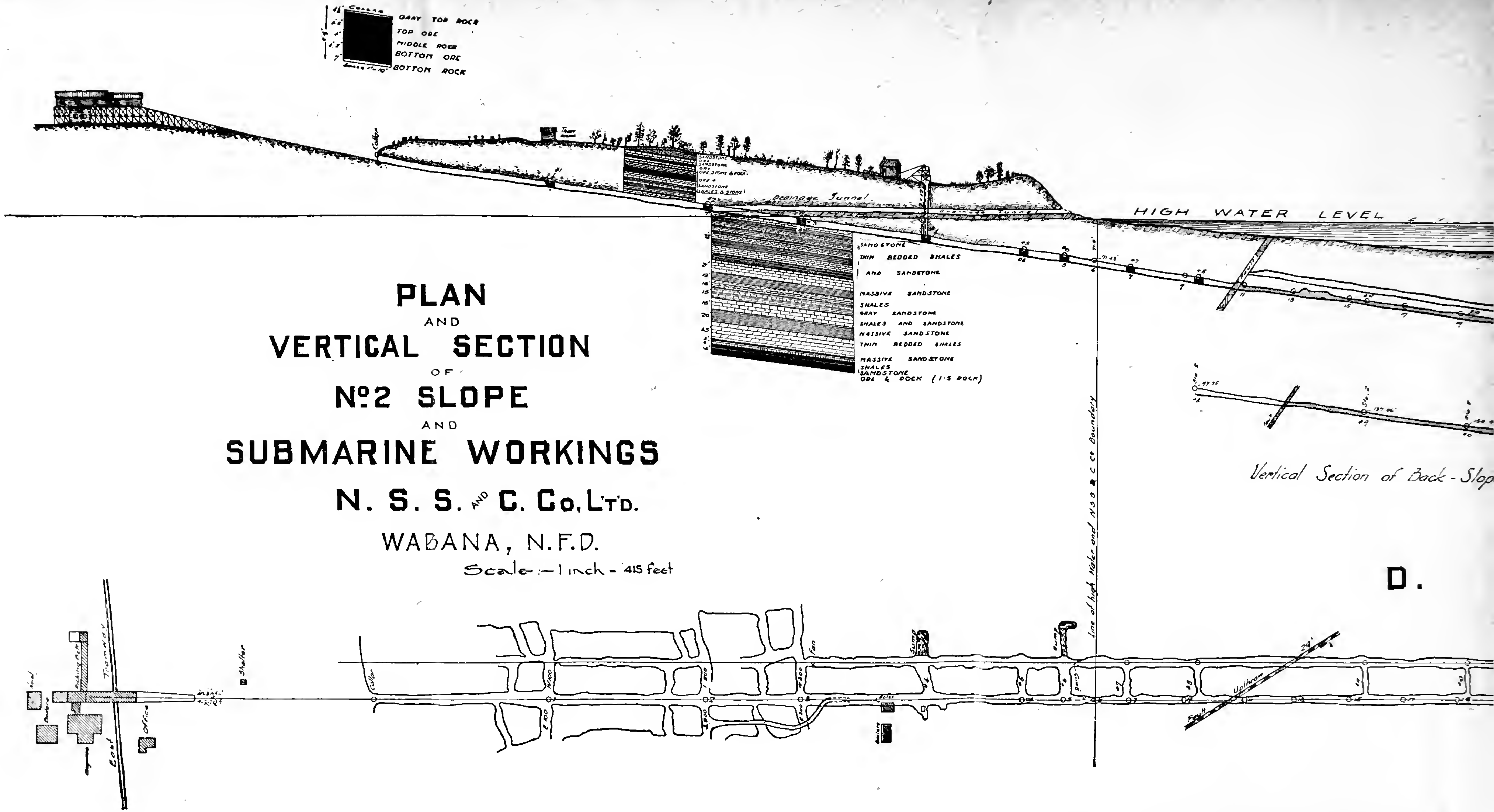

Face
#2 Slope
Feb 1, 1911.
Inner Boundary Scotia Submarine Areas.
Bell Island.
H
A
E
G
on along North and South Meridian
the Cambrian Series in Conception Bay, Newfoundland.
ccurence of the Hematite Iron Ore Deposits
om data of the Geological Survey of Newfoundland.
feet

FIG. 3



PLAN
AND
VERTICAL SECTION
OF
No.2 SLOPE
AND
SUBMARINE WORKINGS
N. S. S. AND C. Co. LTD.
WABANA, N.F.D.
Scale:- 1 inch - 415 feet
GRAY TOP ROCK
TOP ORE
MIDDLE ROCK
BOTTOM ORE
BOTTOM ROCK
HIGH WATER LEVEL
Drainage Tunnel
SANDSTONE
THIN BEDDED SHALES
AND SANDSTONE
MASSIVE SANDSTONE
SHALES
GRAY SANDSTONE
SHALES AND SANDSTONE
MASSIVE SANDSTONE
THIN BEDDED SHALES
MASSIVE SANDSTONE
SHALES
SANDSTONE
ORE & ROCK (1.5 ROCK)
Line of high Water and N.S.S. & C. Co. Boundary
Vertical Section of Back-Slop
D.
Tramway
East
Office
Shelter
Collar
Sump
Sump
Fault
Upthrow

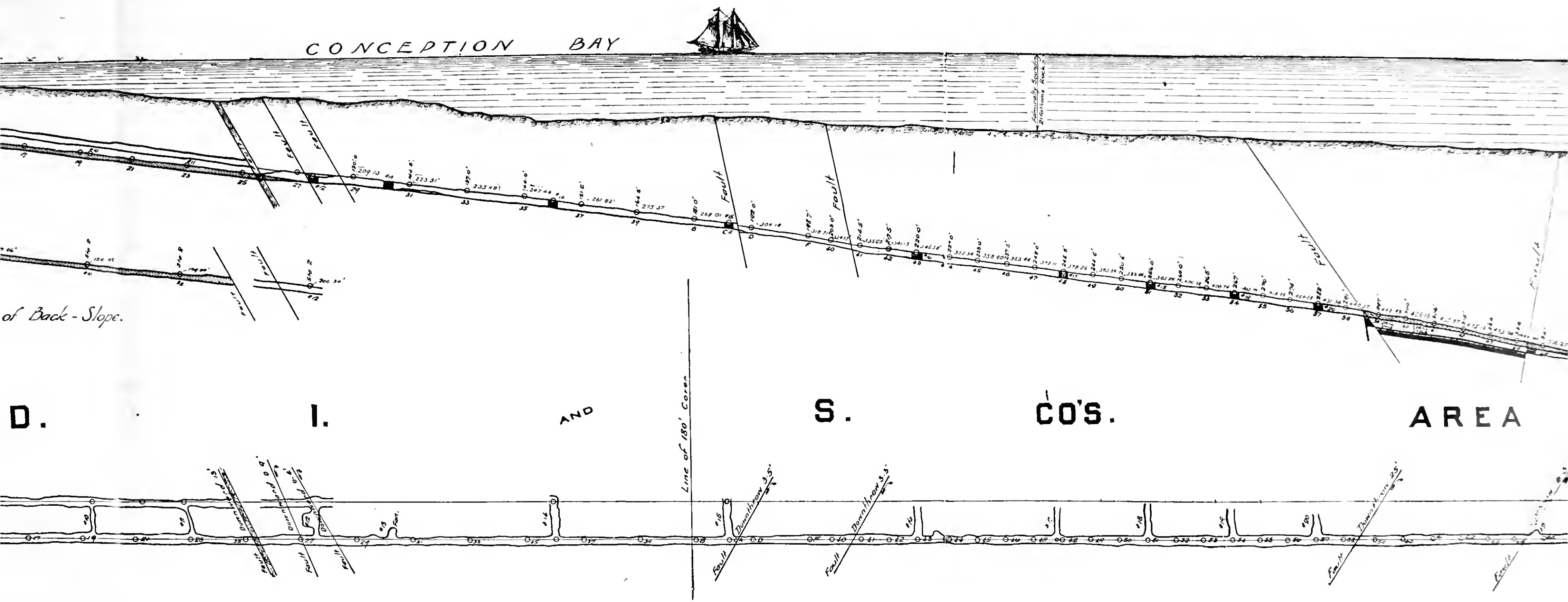
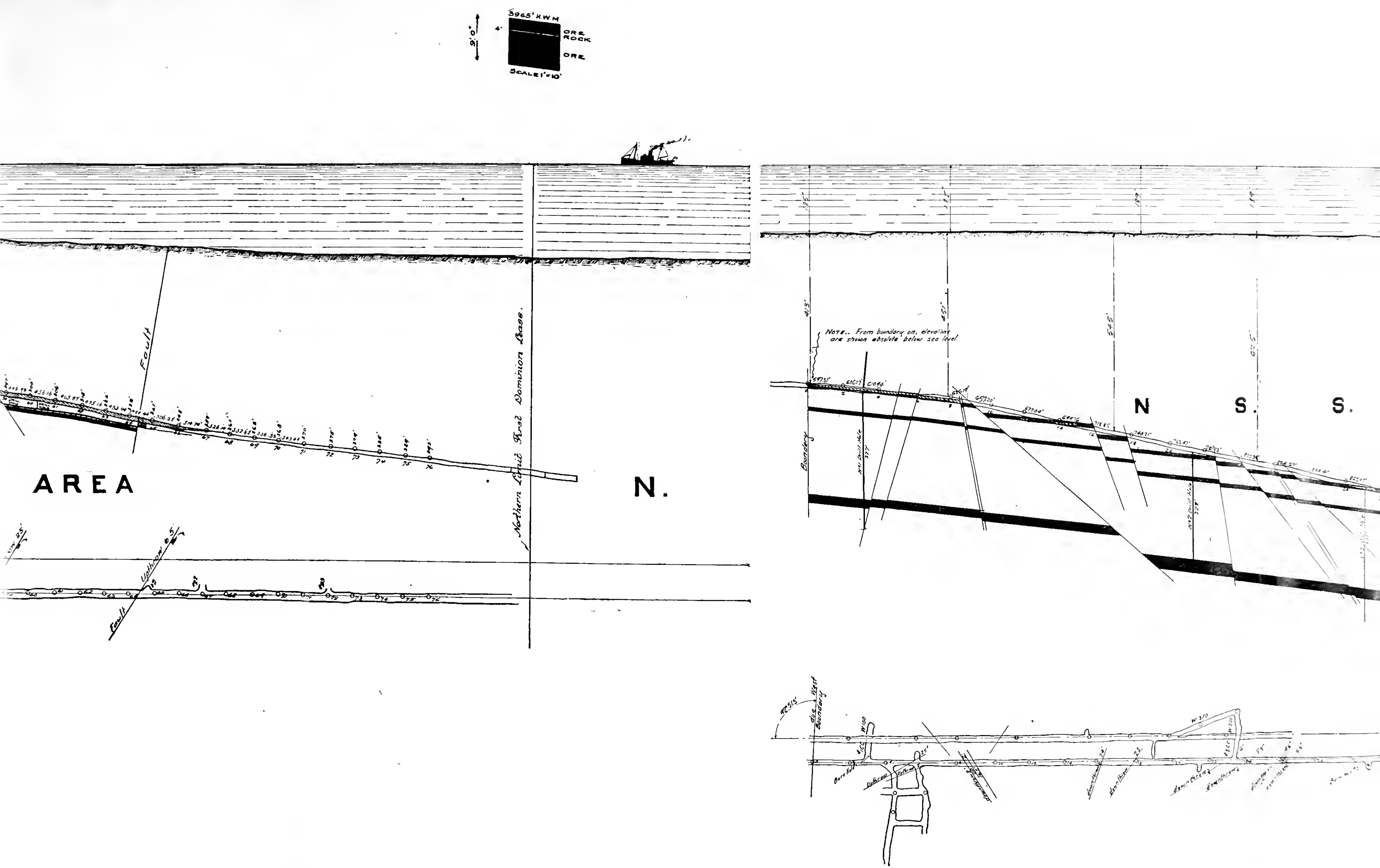
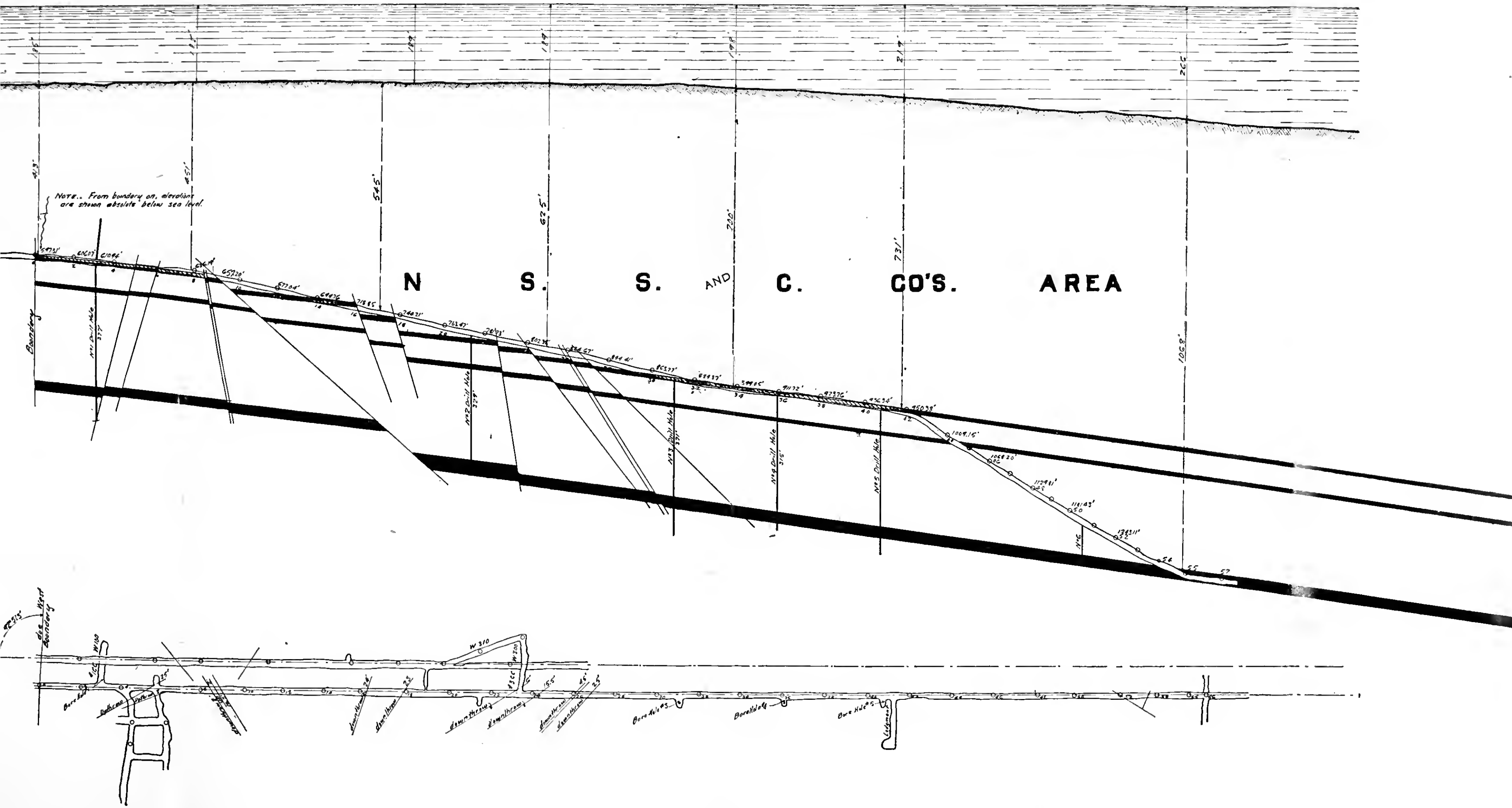

CONCEPTION BAY
Fault
Fault
Fault
Fault
Fault
of Back-Slope.
Line of 180' Cover
D. I. AND S. CO'S. AREA
Fault Downthrow 3.5'
Fault Downthrow 3.3'
Fault Downthrow 2.5'

Fig. 4


5965' H.W.M.
9' 0"
4"
ORE
ROCK
ORE
SCALE 1"=10'
Fault
Northern Limit First Dominion Lease
AREA
N.
Fault
Upthrow
NOTE.. From boundary on, elevations are shown absolute below sea level.
Boundary
No 1 Drill Hole
No 2 Drill Hole
N S. S.
Boundary


NOTE.. From boundary on, elevations are shown absolute below sea level.
Boundary
N. S. S. AND C. CO'S. AREA
No 1 Drill Hole
No 2 Drill Hole
No 3 Drill Hole
No 4 Drill Hole
No 5 Drill Hole
545'
625'
720'
731'
1068'
Bore Hole 5
Bore Hole 4

THE IRON ORES OF THE MATTAGAMI RIVER.

By M. B. BAKER, School of Mining, Kingston.

(Annual Meeting, Quebec, 1911).

Ever since the emergence of the Laurentian plateau from the Archæan sea, a height of land appears to have been maintained between the Great Lakes and the basin of Hudson Bay. Within this basin a series of later sediments of Proterozoic, Palæozoic and Pleistocene ages have been laid. The Hudson Bay basin, therefore, presents a well marked geographical, as well as geological basin, bounded by a distinct rim of Pre-Cambrian crystalline and metamorphic rocks. This latter area constitutes a somewhat rough, undulating surface, dotted by small lakes, marshes, swamps and muskegs, and has a steep grade toward James Bay from all sides, as is clearly shown by the convergence of the many splendid streams which flow down its slopes.

It is primarily the intention of this paper to discuss the iron area within this basin; but in order to make this clearer, the stratigraphy of the area will be briefly described to aid in accounting for the economic occurrences of the district.

STRATIGRAPHIC RECORD.

Recent.—Peat, marl and bedded sands bearing marine shells.

Erosion conformity.

Pleistocene— { Glacial.
Inter-glacial lignite series.
Glacial. }

Erosion unconformity.

Palæozoic.—Corniferous, magnesian limestones, etc.

Erosion unconformity.

Upper Huronian.—Siderite, sideritic conglomerate, quartzite.
Erosion unconformity.
Post Middle Huronian.—Diabase.
Intrusive contact.
Laurentian.—Granite, syenite, and gneisses.

The oldest formation seen in this area, therefore, is the Laurentian. It consists almost entirely of pink granite and granite gneiss, but varies in many places to micaceous or hornblendic granite. Cutting this Laurentian in all directions is a series of typical post-Middle Huronian diabase dykes, which do not seem to differ in any way from the diabases of similar age in other parts of Northern Ontario. Some of these are mere stringers; others attain an extreme width of two hundred and fifty feet. They are dark grey, medium to fine grained diabase, composed of laths of fresh labradorite set in a ground mass of augite, which is partly in felt-like aggregates resembling uralite and partly in larger well-defined crystals and grains. A little original quartz is to be seen in thin sections, and often in hand specimens. Accessory pyrite and magnetite are also present. At several places veins up to three inches in width occur cutting the diabase, but they do not show any of the silver, nickel, or cobalt minerals so characteristic of similar occurrences in the Gowganda or Cobalt areas.

UPPER HURONIAN.

As a fringe along the edge of the sedimentary basin is a formation which the writer has classified as Upper Huronian or Animikie in age. There are but few outcrops and these only along the border. They consist of a rich, dense, brown siderite, which shows a banded structure in places, and is very pure spathic iron, as shown by the following analysis:

Fe	CaO	MgO	CO_2	MnO	Al_2O_3	SiO_2	Sp. Gr.
43.27	1.47	0.91	34.94	1.74	2.31	1.40	3.63

Associated with this siderite is a fine-grained quartz conglomerate shading in places to quartzite. The pebbles of this conglomerate are for the most part quartz, which apparently has been derived from the disintegration of the Laurentian, and cemented by siderite. This Animikie siderite is an important formation, for it is believed to be the source of the iron now found as limonite, to be presently described.

In 1904, J. M. Bell presumably found a similar siderite on the Opasatica river, for he states: (*B. of M., Vol. XIII, p.* 152) "Apparently this carbonate has resulted from the direct precipitation from a sea-water rich in iron, magnesium, and lime on the upturned edges of the gneisses. No fossils are found within the beds and their age is, in consequence, a matter of conjecture, but from the lithological resemblance to the iron-bearing calcareous magnesium rocks of the Mesabi range in the Lake Superior region they have been tentatively classed as Huronian." But he immediately adds "though, as a matter of fact, they may be more correctly correlated with the ferruginous carbonates of the Devonian of the coastal plain." From this we see that Mr. Bell was at least suspicious of the Upper Huronian siderite.

At the head of Grand Rapids on the Mattagami river, the siderite, sideritic conglomerate, and quartzite were found by the writer *in situ* on the shore above water level, and the siderite and conglomerate are easily traceable across the bed of the river to the opposite shore. Chemical analysis of this siderite, and the siderite from the Helen mine in the Michipocoten district, and a typical siderite from the Animikie of Port Arthur district are given below for comparison, and it will be readily seen that this is a very high grade carbonate.

Locality	Fe	CaO	MgO	CO_2	Al_2O_3	MnO	Sp. Gr.
Siderite from Grand Rapids Mattagami river, Ont..	43.27	1.47	0.91	34.94	2.31	1.74	3.63
Siderite from Helen Mines Michipicoten, Ont.	35.69	1.03	7.53	37.18	3.92	..	3.72
Siderite from typical Animikie, Port Arthur, Ont.	28.97	3.59	6.20	29.06	5.41	0.82	3.40

For various reasons, it seems that this siderite and silicious sediment are of Pre-Cambrian age. The absolute absence of fossils, the lack of bedding, the compact structure, their occurrence as a fringe along the edge of the Palæozoic, nearest to the Laurentian floor, the lithological and chemical character, and the texture would appear to correlate them with the Animikie Iron Formation of the Lake Superior area.

PALÆOZOIC.

Lying uncomfortably on the Pre-Cambrian is the Silurian and the Devonian limestone, in practically horizontal undisturbed condition, although in a few places subsequent folding has produced local anticlines and synclines. The general dip of the series is to the south-east; the exposures are in cliffs of earth-drab to dark bituminous limestone, rising abruptly from twenty to thirty-five feet above the water. Fossils are very abundant in these rocks, and a number were collected and subsequently identified by Dr. C. R. Stauffer, Palæontologist at the School of Mining, Kingston, who reports that they are typical Silurian and Devonian (Corniferous) forms.

At the close of Devonian times the sea retreated to the North-east, and we had no further sedimentation over this area, except the loose, unconsolidated drifts, etc., of Pleistocene times. It is not necessary, therefore, to follow the geology of the district further, as we have now sufficient description to proceed to a discussion of the iron occurrences.

IRON.

The iron ore on the Mattagami river was discovered by Dr. Robert Bell, and described by him as follows (*G.S.C.* 1875–6, *pp.* 321): "This locality is remarkable for the occurrence of a large body of iron ore. The position is on the north-west side of the river, at the foot of the Grand Rapids. It runs along the foot of the cliff for a distance of upwards of three hundred yards almost continuously, with an exposed breadth of twenty to twenty-five yards. The highest points rise about fifteen feet above the level of the river. The surface is mottled, reddish-yellow, to brown, and has a rough, spongy or lumpy appearance, like that of a great mass of bog ore. At the surface, and sometimes to a depth of several inches, is a compact brown hematite, occasionally in botryoidal crusts, with radiating columnar structure." The deposit was also examined and reported on in detail by J. M. Bell (*B. of M. Vol. XIII, p.* 152). Both these geologists appear to have seen the deposits at the foot of the rapids only, whereas others of equal size, and possibly of equal richness, occur at the head of the rapids a mile and a half farther up-stream. These deposits occur on both banks of the river, and extend across the river bed at both localities, and in each case are continued along the shore for about 1,100 feet. In places they rise from fifteen to eighteen feet above the level of the river, but their true thickness, since they almost invariably extend below water level, cannot be estimated; nor can it be ascertained how far they occur inland from the banks of the river, as they are covered by thirty to seventy feet of glacial drift, sand, clay, etc. But from the fact that the ore-belt is eleven hundred feet wide and extends across the full width of the river, a distance of a quarter of a mile, it may be concluded that it will continue inland for at least a similar distance. This opinion can only be verified by boring or mining, and as many claims were staked back from the river during the past summer, this information should soon be available.

Occasionally the ore is a soft, often botryoidal limonite in irregular, radiating aggregates. Sometimes it is a dense, hard hematite, or a compact limonite. Again, it may pass into coarse breccia composed of fluted, water-worn fragments of the Corniferous limestone, and rounded boulders of siderite, the whole cemented by limonite. Elsewhere, it is a quartz conglomerate, consisting of small water-worn pebbles of quartz in a matrix of clay and limonite, or again, it may be a clay impregnated by limonite, and all stages of this process being in evidence, as is shown by the following analyses:

		Fe.
1.	Clay of the country in general.	2.46
2.	Clay visibly reddened by the presence of iron oxide.	6.30
3.	Clay of ochreous colour.	11.38
4.	Clay decidedly limonitic.	28.25
5.	Clay-like in appearance, but in reality a low-grade ore of limonite.	33.19
6.	Clay-like in appearance, but in reality a good limonite ore.	48.45

In the case of these clay-iron ores, the passage from one to another type is so gradual, and the clay characters are so well preserved, there is no possible doubt that they form one series. The ores occur, then, in mixed deposits, which, in some places, are high enough in iron to constitute a good ore, while elsewhere the percentage of iron in the alluvial accumulations is too low for an ore. This fact is well demonstrated by the following analyses of selected samples from the ore body.

No.	Iron	S.	P.	Moisture	
1	52.45	0.14	0.08	1.16	Average of the best ore at the foot of the rapids on the north side.
2	52.10	0.11	0.14	0.94	Best ore below high water mark, foot of rapids on the north side.
3	41.68	0.15	0.12	1.7	Average ore from the foot of the rapids south side.
4	37.35	0.16	0.13	1.56	Average of the best ore at the head of the rapids, south side.
5	36.68	0.60	0.09	1.42	Average of 850 feet of exposure at the head of the rapids, south side.

ORIGIN OF THE ORE.

Speaking of the Mattagami river deposit, J. M. Bell says: (*B. of M. Vol. XIII, p.* 152) "The limonite occurs at the base of cliffs of limestone lying almost horizontally from thirty to forty feet high, overlaid by fine-grained boulder clay and silt. Its continuation towards the interior is hidden by these overlying rocks, and its appearance at the foot of the cliff is often obscured by talus, resulting therefrom. All the limestone overlying the ore contains iron carbonate, the lower part, or that in close proximity to the ore, being often decidedly ferruginous. The mass of ore has resulted in part from the direct oxidation of the siderite in this iron-bearing limestone, and in part by the replacement of calcareous and other impurities contained within the limestone, either by hydrous iron-oxide deposited as siderite and subsequently oxidized, or directly as hydrous iron-oxide in cavities. This ferruginous material is brought in solution as carbonate by waters containing carbon-dioxide and is doubtless leached from the *wide areas of siderite-bearing limestone above the ore strata.*"

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Fig. 1

Fluted, pot-hole-like enlargement of a joint plane in limestone, showing how cavities were made

From the paragraph just quoted it is evident that Mr. Bell considers that the iron ores were formed from the leaching of the Devonian limestone, or a part of it. The writer does not, however, believe that this is the correct solution of the problem; but, on the contrary, considers the limonite and the hematite to have originated from the oxidation of Animikie siderite, which occurs in place at the head of the rapids, and to which reference has already been made in a preceding discussion of the geology of the district. It is also the writer's belief that this Animikie siderite exists at many places about the margin of the Palæozoic coastal plain. In the reports on the various rivers of this area, one is impressed with the regularity with which iron-holding deposits occur about the edge of the basin, and it would appear that about the margin of the Palæozoic area, where the sediments are naturally thinnest, they are locally so eroded as to actually expose the underlying Animikie, the weathering of which produced residual limonite deposits and hematite in place, or supplied springs or other waters with iron-carbonate, which was oxidized and deposited as limonite, hematite, or even magnetite, in new localities. Professor Van Hise in his treatise on "Metamorphism" (*Monograph, XLVII, page* 233), accounts for such deposits as follows:—

$$4\ FeCO_3 + 2O + 3H_2O = 2\ Fe_2O_3.3H_2O\ (\text{limonite}) + 4CO_2.$$
$$\text{or } 2\ FeCO_3 + O = Fe_2O_2\ (\text{hematite}) + 2CO_2.$$
$$\text{or } 3\ FeCO_3 + O = Fe_3O4\ (\text{magnetite}) + 3CO_2.$$

The natural exposures at no place showed ore in actual contact with the limestone, so that its relationship to the wall rocks could not be observed. The writer consequently arranged for several of these deposits to be stripped, in order that the contact might be displayed, and a party of men doing assessment work also uncovered contacts where the characteristic fluted water-worn cavities were easily seen. (See Fig. 1). In these cavities in the Corniferous limestone, the iron-bearing waters have deposited their loads. It is evident that the cavities were made before the ore was deposited, and not by replacement or any such process, for even in the most likely localities there is only the slightest indication of replacement to be seen. Fossiliferous portions of the limestone show the ore filling the pores of the fossils only, while the calcareous frame-work has not been altered. (See Fig. 2.) In other instances, where the limestone is not fossiliferous, the grains of calcite are clearly intact, while the limonite is disseminated merely as an intersticial filling, or as streaks along lines of weakness in the limestone. (See Fig. 3.) Moreover, the ore is in sharp contact with the fluted, pot-hole-like wall of the limestone. (See Fig. 1.) This clearly indicates that the ore-bearing waters found the cavities awaiting them.

SOURCE OF THE IRON.

In attempting to account for the quantity of iron necessary to form such deposits, the writer is of the opinion that the Devonian limestone is not sufficiently rich to have supplied the amount actually present. In arriving at this conclusion he was fortunate enough to uncover one deposit of good limonite ore and to find the limestone floor on which it rests. (See Fig. 4.) There is a distinct knob of limestone rising up within the ore body, as shown in the photograph. Selecting one of the layers of limestone, which by its thickness and other characters could be easily followed from side to side, samples were obtained from each contact, and at equal distances toward the centre and at the actual centre of the body. The analyses of these samples were made at the School of Mining and are quite instructive, for they show that as we go from the ore into the limestone, there is less and less iron, and a perfect correspondence in the decrease as well.

		Fe %
Sample	A.—At the actual contact left side of the exposure	6.50
"	B.—Two inches in from the contact left side "	3.22
"	C.—One and a half feet from the contact left side of the exposure	1.80
"	D.—Centre of the body	0.65
"	E.—One and a half feet from contact right side of the exposure	1.28
"	F.—Two inches from contact right side of exposure	3.58
"	G.—Actual contact right side of exposure	9.90

The various evidences cited above cause the writer to conclude that the iron occurring in the Devonian limestones

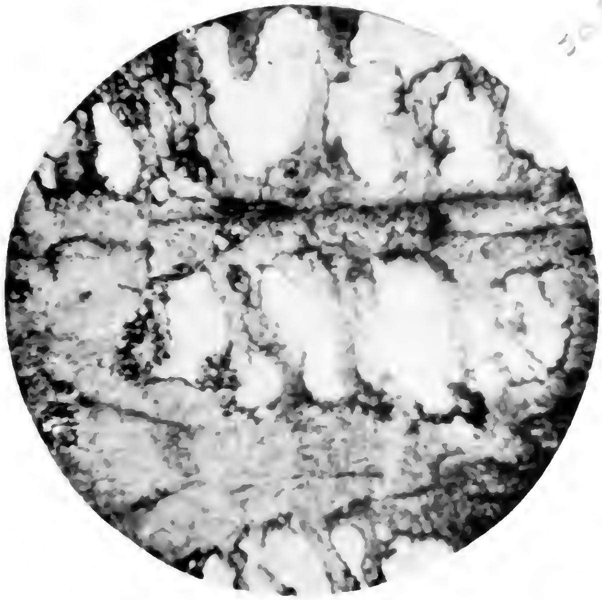

Fig. 2
Limonite filled the pores of the fossil coral, not the calcareous structure of the fossil.

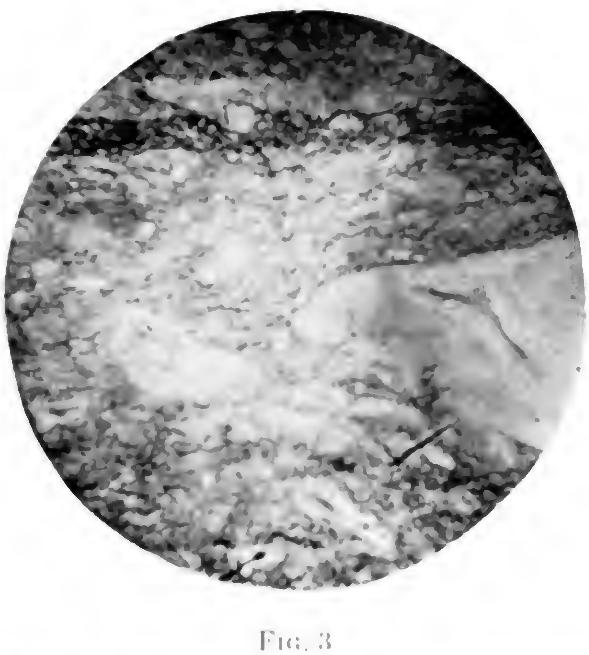

Fig. 3
Limonite along lines of weakness in the limestone, not replacing the calcite.

Fig. 4

Limonite resting on limestone floor, of which the analyses were made showing gradual decrease of iron away from the contact

found its way into them from the cavities rather than in the reverse direction. Attention may also be called to the presence of large blocks of fresh limestone frequently included in the ore-body, which show sharp, clean contacts between them and the ore, with absolutely no sign of replacement or decomposition. They are simply pieces of the wall-rock that have been water-worn, and were later buried by the ore deposition. Moreover, with all the stripping and uncovering of ore that was done during the summer, there was not a single case in which the limestone overlaid the ore.

AGE OF THE ORE.

The ore so far exposed is therefore post-Devonian in age, and most of it is pre-glacial, for rounded boulders of it are found in the glacial drift as far south as the Long Portage, twenty-five miles distant. Moreover, the ore itself is distinctly glaciated in places, one specimen was collected showing distinct glacial striae. A small portion of the ore is cemented glacial drift, and some of it is certainly modern, for it can be seen forming in many local hollows and along the banks of the river in many places, where chalybeate springs issue. This seepage from the banks is so laden with iron-oxide that several prospectors reported the country to be rich in petroleum, mistaking the scum of iron-oxide for oil indications. These latter cases form, however, much the smaller and poorer grades of material. The iron content of such glacial drifts is so low that, in the writer's opinion, they do not constitute an ore. Practically all the *ore* is pre-glacial in age.

ORIGIN OF THE CAVITIES.

As to the origin of the cavities or pockets that now hold the ore, we can only surmise. One thing is evident, however, that they are water-worn erosion channels and, to some degree, solution spaces in the limestone. Their general character is well shown in Fig. I, representing what was originally a joint-crack of the limestone, that has been widened by solution and erosion to a large cavernous passage. This particular crack extends, not only down the full height of the cliff to the water, but from the top of the cliff can be seen to extend with the same course out into the rapids as far as it could be followed.

It is very doubtful if the coastal plain was again under water after the Devonian limestone was deposited until Pleistocene times, for no higher sedimentary horizons have been discovered in this area, and it is not conceivable that glaciation and erosion would have removed every vestige of them had they been present. If, therefore, this area was a land-surface from the close of the Devonian till the Pleistocene, with an established drainage system, we can easily imagine that the thinner places, for example the edges, would be eroded through in many places to the underlying Pre-Cambrian, and many of its main fractures enlarged to irregular cavities by drainage water. The writer's discovery of what is believed to be Animikie siderite at the head of the rapids within this basin has already been mentioned, together with similar discoveries of siderite by others. It is firmly believed that other outcrops are covered only by glacial drift, as these would be were they not exposed by the present rivers having cut through this drift to bed-rock. Because of these basins, pockets, and drainage channels in the limestone, and the rich deposit of siderite in the immediate vicinity, it is readily conceivable that the iron carbonate was dissolved, carried with the drainage waters, oxidized, and deposited in the various forms in which it is now found.

In places where the limestone has been eroded or dissolved through to the underlying siderite, residual deposits of limonite on the surface would result, would change with depth to siderite, and account for occurrences such as Dr. Bell reported thus: (*G.S.C.* 1875, *p.* 321) "At the surface it is a compact brown hematite, but deeper down it is a dark grey compact, very finely crystalline spathic ore, apparently of pure quality. The brown hematite evidently results from the conversion of the carbonate." It will be noticed that the only places where iron ores are reported about this basin are where the present rivers have cut through the drift to bed-rock. In all other places, from twenty to seventy feet or more of glacial drift cover the rocks.

It is possible that this Animikie siderite itself could easily become an ore. It is exceptionally high grade, as shown by the following complete analysis:—

SiO_2	FeO	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	CO_2	H_2O	C	S
1.40	54.31	1.67	2.31	1.74	1.47	Trace	34.94	0.50	1.27	0.0

This analysis gives 43.27% iron, and by simply calcining the siderite over a Bunsen burner, the carbon-dioxide was driven off, and the product analysed 63.74% of iron. In many parts of Europe spathic iron ores of much lower grade than this one are calcined, and thereby produce good ore. Occasionally this calcining is done in open heaps, sometimes in continuous kilns or in roasting furnaces, using gaseous fuels. It is possible, therefore, that with the abundance of local fuel, for example, lignite, peat or charcoal made from the birch forests of this north country, the high grade siderite could be easily converted into a high grade ore. It would appear that this is a phase of the question worthy of some consideration, and it is significant that on the north side of the old Archæan axis, Proterozoic sediments were laid down just as on the southern side. Since rocks of similar character are reported by Dr. Low (*G.S.C. Vol. XIII*, 1903), and by Dr. C. K. Leith (*Econ. Geol. Vol. V, p.* 227) on the east side of James Bay, it seems fair to anticipate that there is a considerable development of these sediments in this basin. If this be true, it seems reasonable to expect that, with better opportunities for exploration, economic deposits of similar kinds, if not of similar extent, to those in the Lake Superior basin, may be found.

NOTE.—This paper is published by permission of the Bureau of Mines of Ontario, for whom the investigation was made by the writer.

SOME NOTES ON PYRITE AND MARCASITE.

By E. B. WILSON, Editor *Mines and Minerals*, Scranton, Pa.

(Annual Meeting, Quebec, 1911).

After examining a tin-white cubical specimen of striated pyrite, curiosity led the writer to examine the books of fifteen mineralogists, to find if possible the exact difference between marcasite and pyrite. While unsuccessful, nevertheless sufficient information was gleaned to emphasize three material facts, namely:—

That the writers of the mineralogies were rarely original;

That they were not sure of the difference between marcasite and pyrite;

That they all agreed on iron disulphide being a common dimorphous mineral;

Thinking possibly that geologists might supply the lacking information, several standard works were examined, but beyond finding that pyrite was found in igneous, metamorphic and sedimentary rocks of all ages, nothing new was ascertained.

Chemists' and geochemists' works were next examined without obtaining any definite information, but from the various kinds of literature there was gleaned so much material that ran contrary to natural conditions, that these notes were written with the hope that they will arouse sufficient interest to start an original and substantial investigation.

Geochemists seem to have given little attention to that mineral which probably more than any other has been the medium through which the most valuable ore deposits have been formed, or if this statement is incorrect it is because they have failed ntterly to record their investigations.

When a new bed of coal is discovered, almost the first thing considered is its percentage of sulphur (pyrite). Frequently coal has been condemned hastily and wrongfully on this account, the samples analyzed having included the sulphur bands. It is improbable that sulphur ever exists in coal beds in combination with the carbon of the coal, for nature has segregated and usually separated the pyrite in layers or bunches. To find sulphur in coal cleatage is unusual, and when it is so found evidences of other impurities accompany it. Charcoal, mother coal, carbonaceous shale, clay and other rock material will precipitate pyrite from sulphate solutions, but probably not coal unless high in ash, according at least to the writer's observations. Charcoal, mother coal and shale do not contain bitumen, yet they precipitate iron disulphide from solutions, by some unknown method.

Bloxam states "that pyrite is formed from ferrous sulphate by organic matter and its presence in coal appears to be accounted for in this way." This is in direct opposition to the hypothesis, yet it is believed that if Mr. Bloxam had examined coal beds, he would have found the sulphur in slate partings or in contact with the roof or floor rock enclosing the seam; further that it was not precipitated by the carbon of the coal. Organic matter precipitates gold from auric chloride or gold cyanide solutions; it precipitates copper pyrite from copper sulphate solutions; and blende from zinc sulphate solutions. In fact the organic matter need only be charcoal to bring about the reaction. The writer can find no evidence that coal will precipate these minerals from solution. It seems to be more than a coincidence that pyrite is found attached to shale and rock rather than to coal.

The following formulas are advanced as possible reactions, which however the writer has not verified:—

$$2FeSO_4 + 2\ CaCO_3 + 2H_2O = FeS_2 + FeCO_3 + 2CaOH + H_2CO_3 + 8O.$$

It is known that ferrous carbonate is soluble in carbonic acid and if hydrogen sulphide happened to be present the ultimate reaction might have been as follows:—

$$FeCO_3 + 2H_2S = FeS_2 + H_2CO_3 + H_2.$$

As pyrite in coal beds is in physical combination and not chemical, mechanical washing is practised to reduce the percentage of sulphur, sometimes with entire satisfaction.

The iron master maligns pyrite even more than the coal miner; in fact has no earthly use for it, yet he would be without a furnace had not pyrite furnished him hematite and limonite according to the following reactions:—

$FeS_2 + 2O = FeS + SO_2$.

$FeS + 4O = FeSO_4$.

$6FeSO_4 + 3O + 3H_2O = 2Fe_2 (SO_4)_3 + 2Fe (OH)_3$. Rusty quartz stain reaction.

$FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4$ and

$2FeCO_3 + 5H_2 O + O = Fe_2O_3.3H_2O + 2H_2CO_3$. Limonite reaction. In the case of a ferric salt,

$2Fe_3(SO_4)_3(OH)_3 + 6CaCO_3 = 2Fe (OH)_3 + 6CaSO_4 + 6CO_2, + 2Fe_2O_3$. Hematite reaction or if the solution was ferric chloride,

$2FeCl_3 + 3CaCO_3 = 3CaCl_2 + 3CO_2 + Fe_2O_3$. Hematite reaction.

Passing to the copper matte smelter, it will be observed that he must have pyrite to produce matte, however his case is exceptional. The lead smelter does not particularly care for pyrite if he can obtain iron oxide, but is forced to accept some of it as a rule. The zinc smelter penalizes the miner heavily if zinc ore contains more than two per cent. iron, which is equivalent to 4.25 per cent. pyrite, yet were it not for the weathering of pyrite the zinc smelter would have few rich oxidized ores and not so bountiful a supply of blende.

So much has been said and printed concerning the weathering of zinc-lead ores and their secondary concentration that it is necessary in this paper, to call attention merely to the relative weathering capacities. Iron has more affinity for sulphur than zinc or lead. It is therefore more easily weathered and less easily precipatated, a feature that aids in dissolving the other metal sulphides in the order given.

From the mineralogist's standpoint marcasite differs from pyrite in its color, being tin-white instead of brass-yellow; in its specific gravity being from 4.6 to 4.9 instead of 4.9 to 5.2, and in its crystal form being orthorhombic instead of isometric.

Pyrite like some other minerals is polymorphous in that for some unknown reason it has more than one crystal form.

C. Mene observed some time prior to 1877 that iron disulphide of unaltered sedimentary beds is mostly marcasite, while that of metamorphic rocks is pyrite. ([1]).

([1]). Dana's System of Mineralogy, 1877, p. 800.

Isolated crystals of pyrite are found in sedimentary rocks, and white iron pyrite is found in the metamorphic rocks in the anthracite region of Pennsylvania as well as pyrite. In Nelson County, Virginia, isolated cubes of white pyrite are found in aqueo-igneous rocks with striations as perfect as on brass-colored cubes. From observations, the writer is satisfied that it will require more than the dimorphism of iron disulphide to distinguish pyrite from marcasite. Stokes has noticed that much of the fibrous mineral usually called marcasite consists actually of pyrite (1) and the writer has seen pyramidal pyrite as brassy as any cubic pyrite.

"From the circumstances that marcasite is the characteristic form in sedimentary rocks, while pyrite occurs in plutonic rocks, Van Hise infers that marcasite is transformed into pyrite by pressure." (2) In regard to this Dr. Elsden says: "The transition does not appear to have been realized in the laboratory and nothing is definitely known of the conditions under which it takes place."

Aqueo-igneous rocks contain isometric brassy and tin-white pyrite. This does not fully agree with Prof. Van Hise's theory, although it will be noticed that the brassy coloured pyrite favors quartz, particularly if copper is present. "Iron disulphide is made artificially by heating iron with an excess of sulphur or heating ferric oxide or hydrate moderately in hydrogen sulphide so long as it increases in weight." Iron disulphide made artificially for the generation of hydrogen sulphide by melting iron and sulphur, crystallizes when cooling in the isometric system, its appearance, however, does not approximate brassy pyrite, owing to the latter being formed from aqueous solutions.

Moses and Parsons in their Mineralogy state that "pyrite is being formed to-day by the action of hydrogen sulphide of thermal springs upon soluble iron salts. It has been developed in many rocks by the action of hot water on iron salts in the presence of decomposing organic matter." Both the above reactions are probable although it is not necessary to have hot water; for example, "alum shale" is composed of carbonaceous matter, pyrite and clay. The pyrite when exposed to the weather will

(1). Bull. No. 186, U.S. Geol. Survey, 1901.
(2). Elsden Principles of Chemical Geology, p. 111.

oxidize, form sulphuric acid and ferrous sulphate, that will act on the aluminum silicate and form aluminum sulphate. It is assumed that a reaction something similar to the following takes place based on the fact that silica abhors sulphur and cannot be forced into combination with it in a blast furnace.

$2FeSO_4 + Na\ Al\ Si_3O_8 = FeS_2 + Fe\ Al\ Si_4O_{10} + 6O.$

Dr. J. V. Elsden (1) in treating on Equilibrium Conditions of Polymorphous Forms says: "At any given temperature and pressure one of these forms is in general metastable with regard to the other, and the metastable form tends to pass spontaneously into the more stable variety. These polymorphous forms differ not only in their crystalline form and symmetry but also in their specific gravity, melting point and other physical properties. Theoretically it would be inferred that the denser forms are the more stable under high pressure." That there is a slight difference in specific gravity between the brassy and white iron pyrites is due probably to impurities. Pure pyrite should contain 46.7 per cent. of iron, and 53.3 per cent. sulphur. Analysis of Louisa Co., Va. pyrite is as follows: S 47.78, Fe 43.90, Cu 3.69, Zn.24, SiO_2 1.99, As.63, P.10. H. Reis authority. An analysis of marcasite made by C. Mene, gave Fe 38.9, S 44.9, SiO_2 11.3, Al_2O_3 2.4, H_2O 1.7, and CO.3. The sample came from a bituminous coal bed according to the information given, although the writer thinks it came from a slate band. In Germany what is termed marcasite is found in such quantities below lignite beds as to make it worth mining for sulphuric acid manufacture. In Ohio it is found near the floor of a coal bed in the forms termed sulphur balls in just the right position to break the knives out of chain coal cutters. It is difficult to reconcile the mineralogists' and geologists' statements, for if the former are right the latter are wrong, and *vice versa*, besides when considered collectively the statements do not always agree with natural facts. Frequently pyrite contains gold, copper and other heavy minerals, and naturally these impurities would increase the specific gravity and in the case of copper alter the colour. Pyrite containing copper sulphide is more readily weathered than pyrite, which leads to the supposition that degree of weathering is not to be depended on as a distinguishing feature.

Summing up it is found that none of the surmises or theories of the mineralogists, geologists and geochemists so far as pyrite is

(1). Principles of Chemical Geology, p. 98.

concerned are entirely tenable, and that the true difference between pyrite and marcasite, if any exist, will be found in their chemical composition. It also may be possible to tell from these analyses the amount of an impurity necessary to alter the form of a crystal from cubical to rhombic, besides obtain other data that will advance the now almost scientific study of ore deposits.

From the casual study outlined in these running comments, the deductions are:—

That iron sulphide is precipitated from solutions by substances that may unite with the sulphide in sufficient quantity to change its crystal form.

That the colour and specific gravity of iron sulphide deposited from solutions may be changed by the impurities entrained during crystallization; further that carbonaceous matter will furnish a whiter colour and less specific gravity than a metallic substance.

That neither coal nor quartz alone will precipitate pyrite.

That organic matter free from bitumen, most metallic oxides, some sulphides and some metals will precipitate pyrite.

That marcasite and pyrite are not safely distinguished by the physical or mineralogical tests advanced.

NATIVE COPPER DEPOSITS.

By ALFRED C. LANE, Tufts College, Mass.

(Annual Meeting, Quebec, 1911.)

Native copper occurs in various places as a casual product of sulphide deposits, in which case it is not the important ore, but simply a rare accessory. There are, however, regions in which native copper is the essential ore. By far the most famous of these is that of Keweenaw Point, off the south side of Lake Superior, in Michigan. Native copper also occurs in various places around Lake Superior beside Keweenaw, as, for instance, on Isle Royale, on Mamainse Point and Michipicoten Island. But there are other regions in which native copper occurs as the characteristic ore. The mines of Corocoro in Bolivia have recently been described by Steinmann.[1] It was also the ore of the Colonial Copper Company at Cape d'Or, on the Bay of Fundy, and it is found along the Connecticut valley and from the palisades of the Hudson to Maryland. I have also seen a sandstone from a western locality which was cemented together by native copper. I am also told that in the famous melaphyre region on the west bank of the Rhine about Oberstein, where many so-called Lake Superior agates have been polished, native copper has been found.

It may be well to call attention to certain characteristics which these deposits have in common.

(1). They all occur in connection with red sedimentaries. The Triassic—and to some extent, the Permian—of the Saar region are the well-known red sandstone of the older geologic

[1] Fest schrift. Harry Rosenbusch, p. 335. Mr. R. Harris has also kindly given me personal information.

writers, and when the Lake Superior deposits were first studied they were in appearance so much alike that by some writers they were attributed to the same period. The associated sandstones are also red in Bolivia.

(2). The deposition of the copper in all cases, I believe, is attended by a blanching of the sandstones. Whether this is due to an actual removal of the ferric iron or to its reduction to a ferrous iron, or to the development of some mineral like epidote, which, though it contains ferric iron, is not red, I will not pretend to say.

(3). This formation of red sediments is also associated with basaltic dark coloured lavas containing a very large amount of ferrous iron and a small percentage (about 0.02 per cent.) of copper. This quantity of copper is on the whole quite uniform, since we find it not only in Grout's average analyses reported in Science,[1] but also in Laspeyre's analysis of the Norheim tunnel.[2] It is also the approximate percentage of copper found by myself as the average result of tests on the sludge from some 6,000 feet of drilling across the Keweenaw range. The commonest type of these basaltic lavas seems to be very close to that which years ago Bunsen, in studying the lavas of Iceland, described as the normal basalt, which I have given reasons to believe[3] is in composition the most fusible of the common series of rocks.

(4). I should like to add another point, about which one cannot be so certain, and I add it rather as a suggestion: *i.e.*, that in all cases native copper was associated with waters containing a high percentage of earthy chlorides. This is not true as regards the surface rocks where the salty water has been leached out; but the peculiarly saline character of the deep water of the Keweenaw of the copper mines is now well established.[4] Steinmann (*loc. cit.*) refers to the salty character also of the Bolivia mines, and certain analyses of deep wells in New Jersey suggest that a similar water is found in the Triassic there, while Laspeyres gives an analysis of water from Durkheim[5] which

[1] Sept. 2, 1910.
[2] Zeits. D. Geol. Ges. xix, p. 855.
[3] Tufts College Studies, "Wet and Dry Differentiation," Vol. 1, part 3, p. 40.
[4] Lake Superior Mining Institute Proc. 1906, xii, p. 154.
[5] Zeits. D. Geol. Ges. 20 (1868), p. 191.

seems to suggest a similar water associated with the German melaphyre.

(5). The native copper is not usually found in fissure veins, although it does occasionally so occur, being characteristically irregular, and of the nature of a replacement or an infiltration in the surrounding country rock.

(6). Another point of resemblance not absolutely universal[1] is the association with zeolitic minerals characteristic of the traps which contain water and which, there is good reason to believe, were deposited from hot water.

So much is fact. I think we can, perhaps, weld these facts into a theory consistent with them and that will be at the same time somewhat suggestive as to where to look for the copper.

The formations in which native copper occurs are those which, according to the general belief of geologists, were formed at periods when the land stood high and the ocean relatively low. Moreover, red rocks have by many geologists been considered largely laid down upon the land. This seems natural enough, because there would then be more chance for oxidation of the iron. There are, however, exceptions to this rule.

If we take the admirable series of geographic maps of the North American continent issued by Schuchert, we find that at the time of the Lower Cambrian, say the Upper Georgic, most of North America was above water. And yet Lake Superior is and was a great basin, and it would seem probable that deposits would have gone on forming in this basin even during the considerable elevation of the continent which took place between the Pre-Cambrian series, and the great depression of the continent and consequent overlap of sandstone that produced the formation popularly designated the Potsdam. My present interpretation of the Keweenaw formation is that during this interval when most of the continent was out of water, in the early Cambrian (and perhaps somewhat earlier), the copper-bearing formation of Lake Superior was laid down as a great series of lavas and red beds like those which now occupy many places in the great basin region, the Great Plains of the Snake river in Idaho, for example.

Another characteristic of the Keweenaw sediments is that the material of so large a proportion is derived from the formations themselves. The conglomerates are often composed of amygdaloid pebbles which are apparently originated from the amygdaloid formation, and the fact has been recognised that the Calumet and Hecla conglomerate obtains its material at Calumet very generally from a quartz porphyry of the Keewenaw formation exposed not far distant. A couple of miles south its lithological character has entirely changed. In such a great interior continental basin the erosion took place that produced these sediments, and that erosion may also have leached out the copper contained in the traps. This copper may have remained in solution as copper chloride in the waters buried in the more porous beds and may have collected, possibly, an extra richness in certain pools in the desert. If these pools were invaded by lava streams, as certainly at times happened, the water would be evaporated and a further concentration might proceed. Thus we can imagine the formation to be filled with saline waters containing chlorides of copper derived either from the volcanic eruptions in the first place or from the decomposition of the lavas and possibly concentrated still further by the evaporation of those waters either by the heat of the sun or by lava flows and before they were buried. Such a formation would not lose all its heat for a very long time. Calculations have convinced me that after a million years nearly half might be left and that even after fifty million years the disarrangement of the increase of temperature in the earth would still be very appreciable. As the formation slowly cooled, however, water would be sucked in. Lake Superior is a great basin, and the Keweenaw strata dipped toward the centre of that basin on all sides and in any such absorption of water there would be a tendency for the water to migrate toward the centre, independent of any artesian circulation which also might well have been set up, and of the hydration which also took place.

How, then, was the copper deposited? Experiments have shown that in an unequally heated solution of copper and other chlorides the copper will be deposited at the hotter end if the solution is kept alkaline. If, therefore, the copper solutions can find some rock which will tend to keep them from being oxidized and, at the same time, alkaline, there is no reason why copper should not be deposited. As a matter of fact, we find strong tendency for the copper to occur near channels that may be considered to have been once pervious, such as conglomerates or porous beds of lava flows and fissures. But we also find a strong tendency for the copper to occur rather at the sides of the pervious channels in the country rock and adjacent to, rather than in, the main channel. In other words, it seems to imitate a contact deposit occurring in a pervious bed or in its immediate neighbourhood and filling fissures and joints in a less pervious bed. The traps overlying the copper-bearing conglomerates will show films of copper upon the joints, and the copper-bearing amygdaloids must be followed with considerable care, or highly valuable deposits of native copper will be overlooked stretching off into the foot wall.

If the theory above outlined is true, the fact that copper is quite likely to occur, not in cross fissure veins, but in beds, extending for miles with the layers of the formation, can be easily explained. Take, for example, the so-called Kearsarge lode. This is the amygdaloidal trap of a very peculiar flow or group of flows. This has been mined commercially for fourteen miles, and to my knowledge contains noteworthy amounts of copper for two or three times that distance. This flow occurs immediately on top of a fine grained sandstone or shale of a deep red color. This is the type of deposit that might be expected to form in one of those desert plains or basins to which attention has recently been called by students of physical geography who are familiar with the work of wind erosion and deposition in the west. If over such a plain or a lake occupying part of such a plain a lava stream should flow, we can readily see how the copper salts derived from the degradation which produced all this sandstone would be concentrated in the porous parts of the lava flow. It can also be easily seen that this concentration would receive further enrichment if by the upheaval of the formation the waters were set circulating downward and reacting upon the lava flow thus precipitating the copper wherever the solution was sufficiently hot and alkaline to favour it. Again, one can understand why antimony is so extremely rare in connection with native copper, (since a little chloride salt is added to an electrolytic solution to prevent antimony being thrown down with the copper,) and why we have the copper produced from chloride solution. One can also explain the association of the silver, for, while silver chloride is generally classed as insoluble, it is sufficiently soluble in these salt solutions to accompany the copper to the extent noticed. In the reactions which produce the copper, as stated, the solution must be kept alkaline, and we may therefore expect that alkalis should go into solution, and we do, as a matter of fact, find plain indications that copper has replaced the rock, say the pebbles of the Calumet conglomerate, and that sodium silicate and similar substances have been dissolved and that sodium has accumulated in the mine water. It should be said, of course, to avoid obvious criticisms, that copper ores do indeed occur in the Keweenaw formation, but in many cases they seem to be produced after the copper; and the wonder is not really that we find occasional sulphides and arsenides of copper, but that we find so little sulphur and arsenic. Nor would it be wise to say that copper does not occur or may not occur in commercial quantities in fissure veins, for it has so occurred in times past. The next great copper deposit may very well be a type somewhat different from any one heretofore developed. It may be a stockwork in a fissured felsite. It is perfectly possible that at times the course of the currents which tended to concentrate the copper were sideways or downward, and cross fissures should certainly tend to promote circulation which would facilitate the concentration of the copper into commercial deposits, and, as a matter of fact, the bedded lodes are sometimes richer near certain fissures. This was particularly true in the Central mine, where not only did the vein contain copper, but the various amygdaloids near the vein contained copper.

Two points, which, I consider, are really of some practical value are that in testing or working such deposits of native copper the vein or main channel of circulation may be taken as the leader, but that deposits of copper running off into the walls should be expected; and, secondly, that if I am correct in associating the deposits of the copper with the chloride solutions so long as the water is fresh, it is not unreasonable to expect a greater accumulation of copper below. This may or may not have taken place, according to the direction of circulation. After the saline waters have been struck and fairly established, it is probable that the rock will not become richer with very great depth. For instance, the Calumet and Hecla mine was probably at its best somewhere between 2,000 and 3,000 feet down. The question of exploring such regions (not merely fissure veins) should be developed, particularly the places where pervious or impervious beds come in contact and where rocks of very different chemical character occur. In such places precipitation is most liable to have occurred. To apply this, for instance, to the region of the Bay of Fundy, it would seem that some attention should be given, not merely to the fissure veins which cut the great traps through, but especially to the place where these trap flows come in contact with underlying red beds. The deposits may not be of commercial value, but there is a good degree of probability that there will be some enrichment, and in particular it would seem that if any encouragement is found, the test by diamond drilling or otherwise at a very considerable depth, sufficient to see whether these chloride waters which I have assumed really occur there, ought to be undertaken before I, at least, should be ready to give up hope of commercial deposits. The amount of copper which can be picked up along the beach of Cape d'Or is due largely to the marine erosion attacking some amygdaloids which are dipping toward the ocean. Whether these amygdaloids, if struck somewhere deep down under the Bay of Fundy, would be found to have copper in abundance, and whether the contact of the series of traps with the red Triassic beds beneath would show copper, are questions which the explorations so far conducted have not answered.

It will be noticed that just at the time of the early Cambrian (Schuchert's Plate 51), the North American continent stood relatively high, so at the time of the Triassic the continent was high, and the deposits of the Triassic of Nova Scotia were in a basin far separated from the sea. (Schuchert's map, Plate 86.)

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DISCUSSION.

PROF. KEMP:—We now see from Dr. Lane's paper that at the time these basalt flows were formed they were exposed to severe oxidization. Then they were depressed and covered with salt water and we can understand by the action of the salt solution that copper chloride might possibly be formed. But how is that precipitated?

DR. LANE:—Anything that tends to keep a solution of copper chloride alkaline would tend to precipitate the copper. We have succeeded in precipitating the copper either with calcite or by sodium carbonate.

PROF. KEMP:—The Lake Superior copper deposits have always been an enigma to us because the copper goes so deep and it has been necessary to find some sort of reactions, that would be different from those of other regions. In Lake Superior we are even below the ground waters themselves. Therefore, I think it would be interesting if Dr. Lane would give us the further reaction.

DR. LANE:—Suppose we have a copper chloride solution. The oxidizing effect does not go as far as we are inclined to think. I have a series of analyses of rocks down to three or four hundred feet showing copper and ferrous iron, and the more copper there is, the more ferrous iron. It does not look as though the ferrous iron precipitated the copper, though it might. In the Keeweenaw district the lavas must have contained a great deal of heat. As they cooled they contained a great deal of water. In that solution which might then be concentrated as it worked down by absorption of water in the hydration that produces epidote and chlorite, we find the silver chasing the copper down. In that solution unequally heated (with electric currents too?) we will find that the copper will be precipitated at the hotter and alkaline end of the solution. You have as a result calcium chloride, or sodium chloride. The latter is abundant at the top of the water. Suppose we have in that solution sodium silicate. The latter reacts and we have the copper left free. In the case of the Calumet conglomerate, we even have pebbles of felsite, replaced bit by bit of copper. What has happened is that the sodium silicate has gone into solution and the copper has been precipitated and the silicate has come out.

PROF. KEMP:—What becomes of the oxygen combined with the sodium?

DR. LANE:—We can variously account for the oxygen. In the first place we may suppose there is an actual ionic migration of the oxygen as in a battery fluid to be used in combination at a greater or less distance. I think that this is an important factor for short distances.

In the second place the oxygen may combine with hydrocarbons. If I may have a blackboard I can give an ideal reaction: $2\ Na_2\ Si_4O_9 + 2\ Ca\ Cl_2 + C$ (combined) $= 4\ Na\ Cl + 2\ Cu + 8\ SiO_2 + CO_2$. The carbon of this reaction may be contained in the silico carbide glasses such as those described by Brun from which the amygdaloids were derived. R. T. Chamberlin has actually found hydrocarbon or carbon monoxide gas to be given off by a drill core of Keeweenaw diabase. Inflammable gas has been encountered more than once in Lake Superior mines. We may readily write for free H or hydrocarbon present, H in the above reaction and water in the product. Hydrocarbons may also have been dissolved in the connate waters. The products of the above reaction, salt in the mine waters, silica either as quartz or in epidote, and carbon dioxide in carbonates are the most common concomitants of native copper.

Finally we might assume with Pumpelly that ferrous iron has taken up the extra oxygen and that from ferrous silicates like olivine, and augite, ferric silicates like epidote or indeed hematite has been produced. But I have my doubts as to whether this is always really the case, because the analyses do not seem to show, as I thought there ought to be, correlation between the ferric iron and the copper. There are a number of men who have laid great stress upon electricity in connection with copper reaction. There is one thing about this salt water. As long as we are in the surface water, the soft water, we are liable to get better copper below. The best part of the mine is usually somewhere in the first thousand feet after we strike the salt water. The Tamarack mine now runs about 19 pounds to the ton. I want to emphasize the fact that these deposits are getting extremely low. The successful mines are giving about 25 pounds to the ton. The Mohawk has been running about 13 or 14 pounds; and the Victoria mine is running about 8 to 12 pounds, or about $\frac{1}{2}$ of one per cent. That is the kind of deposits we are working in Lake Superior.

DR. W. G. MILLER:—Where does the aluminum—the free sodium silicate came from?

DR. LANE:—The sodium silicate is carried in solution from decomposed felsites or diabase. If we take the decomposed boulders in the Calumet mine, we find a shortage of sodium silicate. The alumina has remained. It must be remembered that this is only an ideal reaction.

MR. TYRRELL:—I would like to draw the attention of the Institute to the fact that we have on and near the north shore of the continent of America what are apparently large native copper deposits associated with red rocks. In places where I have seen these rocks, they contain such minerals as are closely associated with the native copper deposits near Lake Superior. I have in my office in Toronto a very fine piece of native copper brought from the shore of the Arctic Ocean near the mouth of the Copper-Mine river which I would be glad to show to any of the members if they should be passing through that city and would care to see it.

THE UNDEVELOPED COAL RESOURCES OF CANADA.*

By D. B. DOWLING, Ottawa, Ont.

(Annual Meeting, Quebec, 1911).

In the present paper a review of the area and probable coal content of the various coalfields of Canada, is attempted. Such a survey, however, must be regarded as tentative, exhibiting merely the information available at the present time. The terms "areas" and "coal content" where employed have reference to the mineable quantity of coal available under ordinary mining conditions now obtaining. Explorations each year add possibly new areas to our known coalfields and detailed examinations often curtail the boundaries of those already reported. Our knowledge is thus partly definite and partly general.

The age of the coal beds may be briefly summarized as follows:—

Lower Carboniferous.—Cannel coals of the Arctic Islands. Anthracite at Lepreau, N.B.

Carboniferous.—Bituminous coals of Nova Scotia and New Brunswick.

Lower Cretaceous.—Bituminous and anthracitic coals of Rocky Mountains; Queen Charlotte Islands; small areas on Upper Skeena River, B.C., and areas in Lewes River district, Yukon.

Middle Cretaceous.—The bituminous coals of various horizons in the Cretaceous are here included. On the Prairies of Alberta and Saskatchewan where a minimum alteration has taken place, lignites are found. The areas included here are the Vancouver coalfields; certain exposures in the foothills of the Rockies, the Lethbridge-Medicine Hat area and exposures on Peace River.

*By permission of the Director, Geological Survey, Canada.

Upper Cretaceous and Tertiary.—Lignite beds of Turtle Mountain, Man.

Lignite beds of Wood Mt. and Souris, Sask.

Lignite beds of Cypress Hills, Saskatchewan and Alberta.

Lignite beds of Edmonton formation, Alberta.

Coal bearing rocks of Edmonton formation in foothills.

In the central part of British Columbia a number of small areas contain seams of lignite and coal. The larger basins near the coast, such as the delta of the Fraser river and the north end of Graham Island, have not been thoroughly prospected. In the Mackenzie basin lignite-bearing beds are found at Fort Norman and at the mouth of the Mackenzie. On Peel River an important lignite bed has been located.

Interglacial.—The lignites found in northern Ontario are covered by boulder clay and are reported to be of glacial age.

DETAILS OF APPROXIMATE AREA AND AMOUNT OF COAL SUPPLIES.

Arctic Islands.—Exposures of cannel coal or oil shale are noted by many Arctic explorers. Although these deposits are not at present available they should be included in our coal assets.

The beds are dipping at low angles, hence when mineable seams are exposed it may be assumed that the field is wide. The exposures extend across the following Islands:—

Banks Land................	150 miles	
Melville Island...............	150 "	
Bathurst Island..............	50 "	
North Devon.	50 "	=400 miles

Since the exposures are found over a width of thirty miles, the possible area (mined with difficulty for the most part) may approximate 6,000 square miles. With each foot of coal this area would furnish 3,840 million tons.

YUKON.

						Million tons.
North-east of Dawson,	300 sq. m.,	average		4 ft. coal.	Lignite .	750
Tantalus area,	10	"	"	5 ft. coal,	Bitum.	32
Whitehorse & vicinity	3	"	"		Anth.	9
Pelly River, possibly	50	" unexplored			Lignite	50
Liard River,	50	"	"		Bitum	50
	413	Anth.		9 Bit. 82	Lignite	800

MACKENZIE DISTRICT.

Lignite-bearing rocks are reported near the mouth of Mackenzie river.

			Million tons
Fort Norman area,	200 sq. m.	4 ft. coal, Lignite.	500
Peel River area,	200 sq. m.,	30 ft. seam known, lignite. . .	500
	400 sq. m.	Lignite	1,000

BRITISH COLUMBIA.

Coal areas partially examined and for which an estimate of content might be taken as approximate.

VANCOUVER ISLAND.

Koskeemo area at head of Quatsino Sound.—The area occupied by rocks of lower Cretaceous age covers 10 square miles. Borings in certain localities have demonstrated that over sections of the area a 3 foot seam is mineable. The coal is bituminous of good grade.

Area 5 square miles with 3 ft. coal = 9 millions.

Suquash Area.—This was, perhaps, the first of the Vancouver coal areas to be mined. The Hudson's Bay Company operated a mine near Port McNeil for a few years prior to 1851. The coal seams are thin, none found being, perhaps, over two feet in thickness. The area occupied by Cretaceous rocks is large—14 miles along the coast and about 3 wide (not including the extension beneath the Sound) 42 square miles. As the richness of the area is not proven the estimate is made for:—

Area 10 square miles, thickness coal 3 ft. = 19 millions.

Comox Area.—The northward extension of this area has not been determined. Of the part known, Mr. Richardson enumerates the following coal seams:—

Browns river.	7 ft. seam.
Union mine.	10 ft. and 4′ 4″ coal.
Trent river.	3 ft. and 3′ 8″ coal.
Baynes Sound mine.	6 ft. and 5′ 10″ coal.

Area.—Minimum area exclusive of that at northern end or under Baynes Sound—300 square miles, having an estimated thickness of coal averaging 6 ft. = 1,152 millions.

Nanaimo Area.—In the Nanaimo area two seams of workable thickness are mined—the upper is called the Douglas and the lower the Newcastle seam.

The Douglas seam near Nanaimo is about 8 feet in thickness, but increases to the west to a maximum thickness of about 14 feet.

The Newcastle seam varies from 17 feet west of Nanaimo, to 10 feet at the Wellington Collieries, but may be said to average about 5 feet over the major portion of the field. The basin extends south to Haro straits and, including the submarine portion between the islands, represents an area of about 350 square miles. Borings on Saturna Island demonstrate the presence of the coal at the southern extremity of the basin.

Estimate of content allowing 6 feet for the two seams would give a total of 1,344 millions.

Cowichen Area.—This is a smaller basin of about 50 square miles lying south-west and adjacent to the Nanaimo coalfield. The area appears to contain beds of greater age than those bearing coal in the Nanaimo field. Small portions, where upper measures occur, may prove productive, but for this area a small estimate only is warranted.

9 square miles, 4 feet coal = 23 millions.

Queen Charlotte Islands.

Graham Island.—The original prospecting at Skidegate Inlet was on seams at a locality where crushing and alteration probably by intrusive rocks produced an anthracite. Inland anthracitic beds have also been found, but these areas are not of great importance. The occurrence of bituminous coals is, however, proven at Camp Wilson and Robertson and it is estimated that this underlies approximately 60 square miles. An average of 8 feet of coal for this area is believed to be a conservative estimate = 307 millions.

The north-east end of the island is underlain by Tertiary beds which are projected eastward under the sea. At enormous area is conjectured to be lignite-bearing, a 4 ft. seam being exposed on the coast. Of the area supposed to be coal bearing an estimate of 100 square miles for the 4 ft. seam would give 256 million tons of lignite.

Mainland of British Columbia.

Elk River Areas, Crow's Nest field.—Mines at Morrissey, Fernie, Hosmer, and Michel. Area 230 square miles. Coal seams of workable thicknesses aggregate 177 feet of coal, or a total coal content for the area of 39,000 millions.

On account of the thickness of some of the seams, occasioning great waste in mining, an estimate was based on 100 feet of coal or a total of 22,600 millions.

Elk River areas, Fording River field.—A northward continuation of the Crow's Nest beds to the head of Elk river.

Area 140 square miles with 100 feet of coal = 14,000 millions.

Nicola River area.—Tertiary coal-bearing beds occupy the ancient trough through which the present river valley is cut. Seams of lignitic and bituminous coals have been proven. The steam coals of the basin are mined and utilized for fuel on railways. The productive area is reckoned at 12 square miles which, as a basis of 4 ft. of coal, affords a content of 30 millions.

Princeton area.—The Tertiary coal-bearing rocks of this district are masked on each side of the valley by later volcanic rocks. It is thought that, the extension of the coal-bearing beds in a lateral direction may importantly increase the area in which coal may be mined. Seams up to 18 feet in thickness are known to occur, the minimum thickness found by boring over the area, namely a 5 ft. seam, may be taken as a basis for estimating purposes.

Length of field 13 miles, width 4 miles with possibility of extension under volcanics to a maximum of 5 miles.

Area, 52 square miles at 5 ft. coal = 166 millions.

Tulameen area.—A small Tertiary basin including the exposures of Collins Gulch and Granite Creek. Large seams and coal of good grade contribute to make this small area one of importance. Mr. Camsell of the Geological Survey estimates that the field contains a minimum thickness of coal of 20 feet and an area of 5 square miles—a total mineable content of 64 millions.

Telkwa River area.—In the vicinity of the Bulkley valley, several shallow Cretaceous basins containing coal seams varying from lignitic to nearly anthracitic are found to cover possibly 10 square miles. An estimate for this area of 5 feet of coal would afford a content of 30 millions tons.

AREAS NOT OUTLINED BUT AUTHENTIC EXPOSURES OF COAL RECORDED.

Hat Creek.—North-west of Ashcroft, near Marble Canon. Section of lignite exposed.

1.	Greyish and brownish shales and sandy clays with lignite seams a few inches thick about. .	20 ft. 0 in.
2.	Lignite, with shaly and lenticular layers of siliceous matter, ironstone and shale. Lignite of fair quality forms about two-thirds of the whole, and contains much crumbling amber.	26 ft. 0 in.
3.	Lignite with little or no shale or other impurity. Below very compact, rather softer in the upper layers.	42 ft. 0 in.
		88 ft. 0 in.

The area is not delineated but it may be assumed that this thickness of approximately 50 feet would not extend far. An estimate of two square miles of a deposit of this thickness may be assumed; it, however, represents but a small fraction of the possible area. This area therefore might contain 68 millions tons lignite.

Skeena River area.—Near the head of this river an area of 16 square miles is held as coal land and six feet of coal is alleged. This is a semi-anthracite or anthracite. The estimate for 16 square miles for 6 feet coal=61 millions.

Peace and Pine Rivers.—Beds containing coal seams striking parallel with the Rocky Mountains are exposed over a strip the length of which may roughly be given as 50 miles. The width of this strip will depend greatly on the dip of the beds, but is probably limited to a mile. Near the Rocky Mountain portage seams up to 9 feet are reported. In estimating the amount of coal for this area, 50 square miles should include the present known exposures while a thickness of 3 feet, which is the thickness of the seam recorded on Pine river, might be allowed. This would give an estimate of 96 million.

AREAS WHERE COAL HAS BEEN REPORTED OR AREAS WHOSE DEPOSITS INDICATE POSSIBILITIES FOR FINDING COAL.

VANCOUVER ISLAND.

Koprino area on Quatsino Sound.—Cretaceous rocks observed but as yet no workable coal seams found.

Tertiary rocks at Sooke and other points contain fragments of lignite. Workable beds not found.

Reports of coal at head of Alberni Canal and Clayoquot Sound indicate possible Cretaceous or Tertiary beds in the interior of the island. No workable deposits yet discovered.

MAINLAND OF BRITISH COLUMBIA.

Lignite having been found in the stratified deposits of Tertiary age, attention is called to the following areas:—

North side Mataspina Strait opposite the north end of Texada Island.—Near the mouth of a stream draining a series of lakes small seams of lignite are observed in the sandstones of the coast. The Tertiary area is quite extensive and probably underlies land suitable for settlement.

Fraser River delta.—The following excerpt from Part A, Vol. III, Annual Report Geological Survey contains a general description of this area.

"In this region are situated the cities of Westminster and Vancouver. It includes the delta of the Fraser and also the much larger pleistocene delta of that stream. A considerable expanse of lignite-bearing Tertiary, and also of bituminous coal-bearing rocks of Cretaceous age, occur in this region, the two series presenting a system of outliers and ranges flanking the higher coast mountains of granite..................................

"Workable beds of lignite and coal, in the older as well as in the newer series of rocks are believed to exist, and will be developed when prospecting for them by boring, or drifting to depths beyond atmospheric influence, is undertaken. In the adjacent United States territory the same rocks have been more extensively prospected, and in several places, where exploited, show every indication of the prevalence and continuance of favourable coal making conditions along the whole eastern or mainland side of Puget Sound and Fuca Strait, from the southern extremity of the former as far northward as the valley of the Fraser—in other words, on the Westminster side of the trough as well as on the opposing Vancouver Island side. The older or Cretaceous series of rocks are extensively developed in Canadian territory in the Harrison Lake district, and in the south-eastern portions of the field described.

"The quantity of Tertiary coal or lignite which may be developed by means of judicious boring operations in the vicinity of Westminster and Vancouver, can only be conjectured by the experience at Bellingham Bay, which furnishes one of the earliest examples of profitable coal mining on the Pacific Coast; the basin there and its rocks being continuous, it may be fairly inferred that the coal seams are so also."

Kettle River.—A small Tertiary outlier occurs near the town of Midway. In this lignite has been discovered and mining in a small way attempted.

Bull River.—An eastern branch of Kootenay river not explored is reported to have an area of Tertiary rocks from which pieces of lignite have been collected.

Fraser River.—Between Soda Creek and Fort George and at Quesnelle lignite seams are frequently exposed.

Nechacco River.—Extensive Tertiary deposits are mapped; but lignite in a 4 ft. seam is found at only one locality, namely on the river nearly south of Fraser lake.

Blackwater, Chilacco and Nazco Rivers.—Drift lignite is reported at various points on these streams.

Kohasganko River.—A seam of lignite 4 feet thick is recorded from this locality.

Lightning Creek.—A seam of lignite 6 feet thick, probably west of the Cariboo mining region, is recorded. The locality is described as Cold Spring Home.

Parsnip River.—Large blocks of lignite are seen along this stream near the mouth of Pack river.

Dease River.—A small area of Tertiary rocks occur near the mouth of this stream. Small lignite seams are known. The thickest found (3 feet) was on the Liard just beyond the boundary of British Columbia.

Chilcat Pass.—Coal is reported from 20 miles east of Rainy Hollow. This is probably the same occurrence mentioned in 1887 as being near the head of the Pass on the Dalton trail.

Taku River.—South of Atlin district coal is reported from 12 miles above canoe navigation.

Atlin district.—Coal is reported from the lower end of Sloco lake.

Eastern Face of Rocky Mountains.—Judging by the discoveries of the lower Cretaceous rocks in Alberta in the vicinity of the mountains, it would seem reasonable to expect discoveries of the better class of coals in the northeast corner of British Columbia, and this area should be classed with the possible coal fields which need exploration.

	Anthracite	Bituminous	Lignite
Koskeemo, 5 sq. m., at 3 ft. ..	....	9	
Suquash, 10 sq. m., at 3 ft. ..	....	19	
Comox, 300 sq. m., at 6 ft. ..		1152	
Nanaimo, 350 sq. m., at 6 ft. ...		1344	
Cowichin, 9 sq. m., at 4 ft. ...	....	23	
Graham Island, 60 sq. m., at 8 ft. ...	....	307	
Graham Island, 100 sq. m., at 4 ft. ...	....	....	256
Elk River, 230 sq. m., at 100 ft. ...	....	22600	
Elk River n., 140 sq. m., at 100 ft. ...	....	14000	
Nicola, 12 sq. m., at 4 ft. ...	....	30	
Princeton, 52 sq. m., at 5 ft. ...	....	....	166
Tulameen, 5 sq. m., at 20 ft. ...	....	64	
Telkwa, 10 sq. m., at 5 ft. ...	....	30	
Hat Creek, 2 sq. m., at 50 ft. ...	....	....	68
Skeena River, 16 sq. m., at 6 ft. ...	61	....	
Peace & Pine R. 50 sq. m., at 3 ft. ...	....	96	
1,351 square miles,	61	39,674	490

ALBERTA.

The coal areas of this province occur in three divisions of the Cretaceous. The lowest is exposed in long narrow belts in the outer ranges of the Rocky mountains and the Foothills. These areas besides providing the best coal, are also important in that they contain many thick seams, thus ensuring a large supply of valuable coal. The middle division found occasionally in the foothills is better known as the Lethbridge coal-bearing rocks which are exposed over a large area in eastern Alberta; and furnishes a coal which grades from bituminous to sub-bituminous and lignite. The higher coal-bearing beds are well exposed in Central Alberta and from the well known coal seams on the North Saskatchewan have received the name "Edmonton beds." These, in the western edge of the area, contain seams approaching bituminous, but in the eastern part the coal is sub-bituminous.

ROCKY MOUNTAIN AREAS.

Coleman area.—This area is thirty miles long by one and one-half wide, or forty-five square miles, which on the basis of fifty feet of coal, gives a total content of 2,000 million tons.

Blairmore-Frank area.—An estimate of fifty square miles for the area and a workable thickness of thirty feet of coal gives a total of about 1,500 millions of tons. The coal is of approximately the same character as that at Coleman, although in some instances the ash is higher. It is generally classed as a steam coal and the washed coal yields a good coke.

Livingstone area.—This has not been thoroughly prospected, but on the south branch of Sheep River important seams have been discovered. The area is approximately sixty square miles. From the known exposures there appears to be about thirty feet of coal in the measures, which would give a coal content on this basis of 1,500 million tons.

Moose Mountain area.—As the exposures are in narrow bands surrounding Moose Mountain, an approximation of the area available depends largely on whether it is accessible. Of the twenty-five square miles shown on the map, it may be assumed, perhaps, that fifteen square miles are available, having a coal content of fifteen feet, or approximately, 250 million tons of available coal.

Cascade area.—Although there is a total of over one hundred miles for the length of this basin, a part, that between the crossing of the Cascade and Red Deer rivers, does not contain a sufficient number of coal seams to warrant inclusion. The better part of the coal measures are eroded, so that about forty miles at the south end and about twenty at the north end may be considered as rich measures. In the south end of the measures are over seventy feet of available coal. The lower seams are anthracitic and anthracite and the upper probably bituminous in some places.

In the northern portion one section contains eleven seams or ninety-four feet of bituminous coal. The quantity of coal of the harder varieties in the lower seams has been estimated at 400 million tons; and an estimate of 1,200 million tons representing the upper portion of the measures in the south and the northern portion (considered as bituminous) would not appear to be excessive.

Palliser area.—This is divided by Panther River into two portions. A five foot seam is known to underly at least a small area and a total coal content of twenty millions tons should be available.

Costigan area.—The measures occupy a triangle of which one side—the western—is upturned, forming a trough with gently sloping measures over the major portion of the area. Two workable seams are known having coal approximating the grade of that at Canmore—a steam coal probably too hard to coke. The area available is about twelve square miles and, estimated at eight feet of coal, would provide about sixty million tons.

Bighorn basin.—The measures occupy a trough between the Saskatchewan and Brazeau rivers and it is believed may be mineable over an area 30 miles long by nearly 4 miles. As there appears to be 90 feet of coal in the measures, a carefully calculated estimate by Mr. Malloch is accepted, namely 6,600 million tons.

Nikanassin area.—This area extends from Brazeau river to the headwaters of McLeod river, and lies behind the Nikanassin range, the outlines only having been defined. Length 30 miles, mineable area 2 miles in width, probable thickness of coal 20 feet —estimate of coal 770 millions.

Jasper Park areas.—A small part of one area has been outlined. Prospecting, however, has indicated the existence of other productive areas. Area known, 20 square miles—thickness of coal 20 feet. Approximate estimate, 128 million tons.

Northern Foothills.—Coals of this horizon have been found on branches of Smoky river. These areas will, no doubt, prove of value, but an estimate of quantity is not at present warrantable.

COALS OF THE LETHBRIDGE HORIZON.

Foothills.—The middle horizon, is exposed in the foothills in several bands by the general folding and faulting. The coal content is not large. The coal, prevailingly of the softer bituminous variety, is, however, generally of good quality. The total area is 1,000 square miles, of which possibly 200 square miles are mineable. This on the basis of 6 feet of coal would yield approximately 800 millions tons. The character of the coal is shown in the following analyses returns:—

Locality	Thickness	Moisture	Volatile	Fixed Carbon	Ash
Stoney Reserve, Morley.	6′ 0″	1.26	41.30	48.60	8.84
Bragg Creek.	2′ 6″	9.31	35.59	41.72	13.38
S. Branch, Sheep Creek. .	7′ 0″	2.50	35.88	56.64	4.98

Lethbridge-Medicine Hat area.—The possible coal-bearing area extends from Lethbridge to the Cypress Hills. Northward on Red Deer river, coal seams have been found to underly the country west to Bull Pound creek. The higher class coal is found on the western margin, analyses of which are shown in the following table:—

Located	Thickness	Moisture	Volatile	Fixed Carbon	Ash
Stair No. 6 level.	5′ 0″	20.54	33.26	41.15	5.05
10 miles west of Medicine Hat.	4′ 0″	16.82	31.90	43.98	7.30
McPhee Mine Sec. T., Tp 10, R. 17, W. of 4th.	2′ 7″	11.35	29.98	1.63	7.04
Tabor Mine, lower bench	3′ 3″	7.21	39.18	46.36	7.22
Lethbridge.	5′ 6″	4.73	34.61	50.43	9.89

Mineable coal seams are to be found over an area of 8,000 square miles. Only the shallower portions of the area are at present mineable, consequently 4,000 square miles is conceded as a basis for estimation, and should represent 10,000 million tons of available sub-bituminous coal. The soft bituminous of the western portion may be roughly calculated as representing 500 million tons.

Battle River area.—A northern exposure of these rocks has revealed only thin seams. The area represents 3,700 square miles which may average 2 feet of coal, and hence contains approximately 4,000 million tons of sub-bituminous coal.

Peace River areas.—Coals are known to occur on the Peace River, near Dunvegan, and at the Rocky Mountain Portage. These beds when explored should add materially to the coal assets of Canada.

UPPER CRETACEOUS COALS.

Coals of the Edmonton formation.—The area occupied by these rocks is a large triangle with its western edge parallel to the Rocky mountains and the eastern edge nearly north and south adjacent to Lethbridge coal areas. It forms a trough in the centre of which is the remnant of the sandstone formation of the early Tertiary. The underlying coal is mineable through and near the edge of this formation; but towards the centre of the basin the thickness of the formation in some localities is such as to render the productivity of these areas problematical and they have consequently not been included in the present estimates. The western portion produces coal that may in many cases be classed as a soft bituminous, while the eastern portion contains sub-bituminous coals only.

Red Deer River to Athabasca River.—An area of 3,000 square miles containing the very thick seams of the upper part of the Edmonton formation. The inclusion of one-tenth of this area, since the seams may be inclined so that the mineable areas are narrow, is probably sufficient for an approximation. Allowing for 10 feet of coal the total available quantity would be 2 000 millions.

Rocky Mountain House to Athabasca.—Thin seams only are known to occur in this area; but as the beds are dipping gently the known outcrop may be mineable over areas not yet prospected by boring. The thick seams of Pembina River underlie this field at varying depths. Taking into account one-half the superficial area, or 2,000 square miles and (instead of 20 feet), assuming a workable seam of 10 feet, the resulting calculation is a total of 12,800 million tons.

CENTRAL AND EASTERN PART OF EDMONTON FORMATION.

Pembina area.—A thickness of possibly 20 feet of domestic coal is found in nearly a horizontal situation, at the crossing of the G. T. P. railway on Pembina River. This coal may not underlie the whole area; but some coal is found on the Athabasca river to the north and again on the Saskatchewan to the south. Deep mining operations could be prosecuted over an area of 5,000 square miles. An estimate, consequently of an average thickness of 10 feet may not be excessive, which would represent the area as containing a total of 30,000 million tons.

Edmonton area.—The Edmonton seams lie about 600 feet below the Pembina coal and could, therefore, be mined over part of the area to the west included in the Pembina area. 5,000 square miles having 6 feet of coal would represent 20,000 million tons.

Kootanie measures, Rocky Mountains.		Million tons.		
		Anthracite	Bituminous	Sub-Bit.
Coleman,	45 sq. miles, 50 ft....	....	2,000	
Blairmore, Frank	50 sq. miles, 30 ft....	....	1,500	
Livingstone.	60 sq. miles, 25 ft....	....	1,500	
Moose Mt.,	15 sq. miles, 15 ft....	....	250	
Cascade,	40 sq. miles, 25 ft....	400	1,200	
Palliser,	6 sq. miles, 6 ft....	....	20	
Costigan,	12 sq. miles, 8 ft....	....	60	
Bighorn,	100 sq. miles, 90 ft....	....	6,600	
Nikanassin,	60 sq. miles, 20 ft....	....	770	
Jasper Park,	20 sq. miles, 10 ft....	....	250	
Smoky River,	not explored........	....	....	
	408 sq. miles.	400	14,150	

Belly River Coal.		Million tons.		
		Anthracite	Bituminous	Sub-Bit.
Foothills,	200 sq. m., 6 ft....	....	800	
Lethbridge-Medicine Hat,	4,000 sq. m., 4 ft....	....	500	10,000
Battle River,	3,000 sq. m., 2 ft....	....	....	4,000
	7,200 sq. miles		1,300	14,000

Edmonton measures.	Bituminous	Sub-Bit.
Foothills, Red Deer-Athabasca 300 sq. m. at 10 ft...	2,000	
Rocky Mt. House to Athabasca, 2,000 at 10 ft.......	12,800	
Pembina River area, 5,000 sq. miles at 10 ft........	....	30,000
Edmonton area, 5,000 sq. miles at 6 ft............	....	20,000
Bow and Red Deer, 10,000 sq. miles at 4 ft.........	....	15,000
Total, 22,300 sq. miles................	14,800	65,000

Alberta total—Area, 29,608 square miles............	Anthracite	400
	Bituminous	30,250
	Sub-Bitum.	79,000

Bow and Red Deer Rivers' areas.—Coal is mined on the Bow River at Bow Centre and Crowfoot. These seams may be reached by deep mining as far west as near Calgary. The principal mining centre on the Red Deer River is near the mouth of Rosebud River. While mineable seams are not discoverable over the whole of this area of about 10,000 square miles, an available 4 foot of coal may be expected over about 6,000 square miles, representing approximately 15,000 million tons.

SASKATCHEWAN.

The western edge of the province has a large area of the same rocks as are exposed in the Lethbridge-Medicine Hat area, of Alberta. Coal may be found in the south and western part of this area which is roughly estimated at 4,200 square miles. 2,000 square miles may prove to be productive, which, on the basis of 4 feet of coal, would yield a total of 5,400 million tons.

Laramie Coal.—Although the term "Laramie" is not at present in favour as a formational name, the horizon indicated is probably the same as the Edmonton formation of Alberta. The exposures are confined to the southern part of the province and include the Cypress Hills, Wood Mountain and the Souris coal field. 4,000 square miles are believed to be productive and contain 13,000 million tons of coal in grade near the lignite.

	Sub-Bituminous	Lignite
Western Saskatchewan, 2,000 square miles....	5,000	400
Southern Saskatchewan, 4,000 square miles...	3,000	10,000
	8,000	10,400

MANITOBA.

In southern Manitoba the occurrence of lignite seams in the beds forming Turtle Mountain is known. The coal, however, has never been thoroughly prospected. An available area of 48 square miles is conjectured to contain 160 million tons of lignite.

ONTARIO.

The glacial deposits overlying beds of peat and the remains of forests have formed these into lignite beds. In places the deposits may be mined or stripped. The known localities are those on the slope to James Bay while others have been discovered between Abitibi and Missinaibi rivers. An estimate of 10 square miles with 25 million tons has been made. This, however, may prove to be excessive.

NEW BRUNSWICK.

Grand Lake area.—			
Newcastle coal field.	32	square	miles
Salmon River.	32	"	"
Coal Creek.	48	"	"
	112	"	"

Estimated by Professor Bailey to have a thickness of twenty inches of coal for this area and a total of 155 million tons.

Queen's County.—Near Clones settlement a small coal seam was discovered; but boring to prove the field, was not successful in outlining a working seam.

King's County.—A narrow basin southeast of the Grand Lake area containing exposures of the coal measures merits attention, since small seams have been mined near Dunsinane. An area of 4 square miles having approximately 20 inches of coal may be conceded or a total of 4 million tons.

Kent County.—An exposure of coal 18 inches thick is reported near Kent Junction. Others of 10 inches appear to be common. On a branch of Richibucto River, apparently the richer portion of the area, an 18 inch seam is being mined at Beersville. An approximate area of 3 square miles with this thickness of coal would represent a total of 2 million tons.

Gloucester County.—Thin seams of coal are reported at several localities along the shore of Chaleur Bay and Shippegan Island. They are not of workable thickness.

Northumberland County.—Small seams near Chatham are reported.

St. John County—Anthracitic coal mixed with shale in a seam said to be 15 feet thick was worked by shaft at Lepreau. The percentage of coal won was small, however, and the enterprise was abandoned.

Total for New Brunswick.—Area 119 square miles = 161 million tons of coal.

NOVA SCOTIA.

Pictou County.—

Westville—Principal seams:

Acadia (main)	17 ft.
2nd	12 ft.
3rd	6 ft.
4th	8 ft.
	43 ft.

Seams thin out east and west but often thicken with depth. An estimate of a workable thickness of 34 feet for two areas of 6 square miles would represent 130 million tons.

Stellarton.—Principal seams:

Ford Pit seam	9 to 38 ft.
Cage or deep seam	22 to 40 ft.
3rd seam	11 ft. to 9 in.
Fleming seam	5 ft. to 6 in.
McGregor	14 ft. to 10 in.

An average of 50 feet for the 10 square mile area, represents 320 million tons of available coal.

Vale.—Seams:

George McKay seam	2 ft. 0 in.
Six feet seam	6 ft. 0 in.
McBean seam	8 ft. 0 in.

For an area of 6 square miles, 14 feet of coal, the total would be 41 million tons available coal. Between the Vale and Stellarton areas the depth at which the heavy seams of the Stellarton area occur may not be too great for mining. They should be included therefore, in these calculations, although possibly the thickness of coal may diminish. Allowing 20 feet of coal for this area, 4 square miles would furnish an additional 129 million tons.

Total Pictou—26 square miles—620 million tons.

Cumberland County.—The area from Joggins to Springhill is probably less than 40 square miles, since the dip of the seams increase to the east, thus narrowing the mineable area. Allowing an average of 6 feet of coal, the total would represent 25 million tons.

Springhill area consisting of 4 fault blocks permits of mining operations over an area of 44 square miles. The seams are 9 feet, 10 feet and 10 feet, representing a total of 846 million tons available coal.

Cape Breton County.—Cape Dauphin area, 2 square miles, seams, 6 ft. and 4 ft.—total 12 million tons.

Boulardene,	area	90 sq. miles	14 ft. coal	= 80	million	tons
Sydney Mines,	area	15 sq. miles	18 ft. coal	=172	"	"
Lingan,	area	13 sq. miles	32 ft. coal	=266	"	"
Glace Bay	area	16 sq. miles	30 ft. coal	=307	"	"
Schooner Cove	area	8 sq. miles	37 ft. coal	=192	"	"
Cow Bay	area	4 sq. miles	18 ft. coal	= 46	"	"
Cape Morien	area	1 sq. mile	5 ft. coal	= 3	"	"
		66 sq. miles		1,078	million	tons.

This estimate assumes the continuance of the seams over the entire block. On these land areas one-quarter of the coal has been denuded from the surface so that the totals should be:—

Area, 66 square miles; coal content, 808 million.

Undersea areas (limit 2 miles from shore).

Cape Dauphin to Sydney M..	30 sq. m.,	14 ft.	coal	=26	millions
Lingan,	19	"	32	"	=568	"
Glace Bay,	12	"	37	"	=284	"
Schooner Cove,	12	"	37	"	=284	"
Cow Bay,	6	"	18	"	= 69	"
Cape Morien,	6	"	10	"	= 38	"

85 square miles =1,269 millions.
60% mineable = 761 million.

Total mineable at present condition=1,569 millon tons.

Richmond County.—An area of 80 square miles, mostly fractured by faults, contains the lower portion of the coal measures, in which the seams are thin and not very persistent. In the Richmond colliery were two seams of respectively 3 and 4 feet in thickness standing vertically. According to old reports eight seams varying from 3 to 7 feet in thickness occur near Sea Coal Bay.

Assuming a workable seam of 4 feet over 40 square miles, the total available coal would be 102 million tons (doubtful).

Inverness County.—Port Hood.—The land areas at Port Hood contain apparently thin seams of coal only except near the coast where the dip is towards the sea. Seams may be mineable over a marine area approximating 2 square miles exclusive of an additional possible area south of Smith and east of Henry Island. The possible content for the 2 mile area at 6 feet of coal is 7 million tons.

Chimney Corner.—An estimate by Professor Hind for the marine and coast area of 15 million tons leaves, with an extraction of 60 per cent., a mineable content of 9 million.

Margaree.—The land areas although containing thin seams are an asset and for an area of 6 square miles, 3 feet of coal seems to be assured. This may be mined at some future date and if so a total of 11 million tons may be produced.

Mabou.—Mr. Brown's estimate for 1 square mile is 27 million tons.

Broad Cove.—One square mile containing 8 feet of coal would represent 8 million tons.

Totals for Inverness County.—

Port Hood,	2 square miles	= 7	million tons
Chimney Corner,	2 "	= 9	"
Margaree,	6 "	=11	"
Mabou,	1 "	=27	"
Broad Cove,	1 "	= 8	"
	12 square miles	62	million tons.

ESTIMATE TOTAL FOR MINEABLE AREAS WITH SEAMS OVER 4 FEET.

Pictou,	26 square miles	=620	million tons.
Cumberland,	84	"	=871	"
Cape Breton,	66	"	=808	"
Marine,	85	"	=761	"
Richmond,	40	"	=102	"
Inverness,	12	"	= 62	"
	313 sq. miles		=3,224 million tons.	

SUMMARY.

District	Area	Million tons			
		Anthracite	Bitumiunos	Sub-bituminous	Lignit
Yukon........	413	9	82	....	800
Mackenzie....	400	....	....	....	1,000
Br. Columbia.	1,351	61	39,674	490	
Alberta.......	29,908	400	30,250	79,000	
Saskatchewan.	6,000	....	....	8,000	10,400
Manitoba.....	48	....	....	....	160
Ontario.......	10	....	....	....	25
N. Brunswick...	119	....	161	....	
Nova Scotia...	313	....	3,224	....	
	38,562	460	73,391	87,490	12,485
Total..........			173,826	million tons.	

FIRST AID: ITS RELATION TO COAL MINING.

By CHARLES GRAHAM, Superintendent Middlesboro Colliery, Nicola Valley, B.C.

(Western Branch Meeting, Nanaimo, February, 1911).

The idea of first aid to the injured had its origin in Europe about 1880 by the organization in England of the St. John Ambulance Association, and other similar associations on the continent. Since that time the movement has spread to practically all parts of the civilized world.

Mining is of necessity a hazardous calling, and while the element of danger can never be entirely eliminated, the serious results of injuries and the accompanying suffering can be greatly reduced by the systematic and intelligent instruction of a first aid relief corps, the members of which are thus prepared to render assistance on the spot, before the arrival of the surgeon. In this way, not only may many lives be saved by intelligent assistance, but the subsequent suffering of the injured may often be greatly reduced by careful handling of the patients thus avoiding unnecessary injury, especially in the case of broken limbs.

The needless suffering caused by the ignorance of unskilled persons is as frequent as it is deplorable. By rough or ignorant handling, a simple fracture may easily become a compound one. The method of arresting bleeding from an artery is quite simple, yet lives have been lost through the lack of rudimentary knowledge concerning the application of an extemporized tourniquet.

The value of first aid appliances depends almost entirely on the rapidity with which they can be obtained, and in many cases of accident the benefits of a complete ambulance outfit on the spot are incalculable. The Coal Mines Regulation Act, 1906, (British

Columbia) requires that candidates for 1st, 2nd, and 3rd class certificates as mine managers, hold a certificate from a qualified medical practitioner stating that he (the candidate) is fitted to render first aid to the injured. Also, the same Act requires that the owner shall provide one good and sufficient ambulance box for each 100 men employed.

Knowledge of the principles of first aid should not be confined to the officials of a mine, but should be understood by every miner or underground workman. The writer would suggest that the St. John Ambulance Association be approached for the purpose of forming ambulance classes under its direction in every coal mining town, and that examinations be held and certificates issued to those qualifying under their regulations.

The Government could further such a movement by amending the requirements of the Act respecting the holding of an ambulance certificate to read, "That a candidate for any class of mine manager's certificate must be the holder of a St. John Ambulance Certificate" of a certain grade. The St. John examinations are divided into four grades, the candidate being required to first pass the lower standards before entering for the higher. With candidates for 3rd class or Firebosses' certificates a first year St. John certificate would suffice while the higher standards would, of course, be required from men desiring to qualify for more responsible or important posts. This would insure uniform knowledge of the subject by the candidates for mine manager's certificates, as the instruction would be uniform and along certain definite lines, and the examinations set would be the same throughout the province.

In the case of any person having attended other ambulance classes than those of the St. John Association, provision might be made, (to avoid the possibility of undue hardship in these instances), that upon submission of proof to the local secretary of such attendance, the applicant would be allowed to sit for such higher grade of ambulance certificate as he might desire.

The objects of ambulance training are:—

1st.—To render first aid to the injured.

2nd.—To avoid the infliction of further injury to those injured as a consequence of ignorant or unskilled attention.

3rd.—To make men more resourceful in times of emergency; that they may know how to extemporise stretchers, splints, etc., from any convenient article at hand.

In the second object mentioned, great attention is paid in most text books, etc., to warning ambulance men of the care necessary when handling sufferers from broken limbs, lest the simple fracture become a compound one, and nerves or blood vessels injured.

But there is another very important matter to be considered under the same head, i.e., keeping open wounds free from any further infection, if possible, by their aseptic cleansing and antiseptic dressing as soon as possible. This point is most important because medical authorities are agreed that the great majority of cases of spetic inflammation and blood-poisoning following injuries, are due to the entrance of bacteria within the first few hours. If then, as we are told, that all these wounds are dirty or septic and are liable to become infected by bacteria, how can first-aid men best prevent such infections?

1.—By removing dirty clothing from and not handling these wounds with hands that are not sterile or clean.

2.—By knowing how to clean these wounds and how to apply an aseptic or antiseptic dressing. This requires a practical knowledge of how to cleanse the area around the wound as well as the wound itself and a limited knowledge of the antiseptics used for dressing wounds.

Boiled warm water can always be had if there are no antiseptics immediately available, and the area about the wound can be cleansed with boiled water, thus removing, at least, in part a number of the immediate germs; and then a water poultice should be prepared (by moistening a piece of sterile cotton in the boiled water) and applied to wound. If there are antiseptics present, treat the wound and area in the same way. This understanding of the first principles of antiseptic surgery is most important, for by its practice dirty wounds will be prevented, and many limbs saved. It is a well known fact that if compound fractures or other open wounds become infected or contaminated by bacteria, blood-poisoning will result, often entailing not only the loss of the limb, but loss of life.

The writer would, therefore, earnestly advocate coal operators in this and other parts of Canada, to encourage the organization and systematic instruction of ambulance corps by every means in their power. The provision of all requisite supplies and appliances for use in this connection would be one step towards this end. Apart altogether from humane considerations, which, however, are of course of prime importance, the establishment of an efficient ambulance corps at a colliery is in the interests of management, since it is unquestionable that a man receiving skilled preliminary treatment and attention immediately after injury will make a more rapid recovery than one who is obliged to wait several hours for medical or surgical aid.

Training in first aid to the injured is, moreover, a preventive of accidents, since it is the means of forcibly impressing on the minds of mine-workers the dangers of their vocation, and so renders them more careful, not only of themselves, but of others. Finally it exerts a morally elevating and ennobling influence.

THE CLAY AND SHALE DEPOSITS OF THE WESTERN PROVINCES OF CANADA.*

By HEINRICH RIES, Cornell University, Ithaca, N.Y.

(Annual Meeting, Quebec, 1911.)

During the summer of 1910 the writer, accompanied by Mr. Joseph Keele, of the Canadian Geological Survey, was engaged in a study of the clay and shale deposits of the western provinces, and the present paper contains an outline of the results of that work. The full details will appear in a forthcoming Memoir of the Geological Survey.

By way of preface it may be pointed out that the most important and extensive deposits lie in the Great Plains region, while those along the Pacific coast are second in importance.

Few deposits of economic importance have thus far been found in the Mountain region lying between the Great Plains and the Coast Ranges.

Geologically, the clays and shales show a somewhat restricted distribution, ranging from Jurassic to Pleistocene in age.

For convenience of discussion, the occurrences are divided into three areas, viz., Great Plains region, Cordilleran, and Pacific Coast.

GREAT PLAINS REGION.

The clay resources of this region are of two types, viz., surface clays of Pleistocene age, and Cretaceous and Tertiary shales.

SURFACE CLAYS.

By far the greater number of clay deposits worked in the Great Plains region, are surface clays of unconsolidated character.

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They consist of silty or sandy clays, and some very tough, plastic clays, which are irregularly distributed and associated with sands and gravels. The entire series forms a mantle of a varying and often great thickness, which overlies the bed rock and usually conceals it.

Mode of Occurrence.—The surface clays of the Great Plains region vary in their mode of origin and may be grouped as (1) Lake clays, (2) Flood-plain clays, (3) Delta deposits, and (4) Boulder clays.

The lake clays are those which have been deposited in lakes occupying depressions formed by inequalities in the drift surfce, or by the damming of valleys by ice, the sediment deposited therein representing in many cases the finest rock flour derived. from the continental or mountain glaciers.

The dark grey clay underlying the brick clay in the Red River valley is probably of this type. Many of the brick clays worked in Manitoba are probably sediments laid down in the former glacial Lake Agassiz.*

The extensive areas of surface clays which occur in the Saskatchewan valley between Prince Albert and Edmonton may also be placed here. Similar deposits are found in the Red Deer River valley at Red Deer and the Bow River valley at Cochrane.

These lake clays vary in their character, some being very silty and others highly plastic. A pronounced vertical jointing is likewise sometimes present.

The flood-plain deposits are not uncommon. They are well developed along the valleys of the Red River near Winnipeg, and the Assiniboine River westward from that point. Other well-marked deposits occur along the Saskatchewan River at Edmonton.

The delta deposits are less common and form irregular masses in delta sands. One of the most extensive deposits is found in the Assiniboine delta in Manitoba. This forms a roughly triangular area bewteen Neepawa, Brandon and Cypress River. The delta clays occur in lenses and often contain streaks of gravel. Boulder clays are usually dense and stony and, when other more suitable clays are available, few deposits of this character are utilized.

* Upham, W.: Geol. Surv. of Can., Vol. IV, Pt. E.

Properties of Surface Clays.—The surface clays are utilized at many points for the manufacture of common brick but the product varies greatly in its quality, depending in part on the character of the raw material. Many of the clays are calcareous and often sufficiently so to give a buff or cream-coloured product; moreover, the highly sandy character of the clay renders the brick very porous; and the clay oftens shows a tendency to crack in air-drying unless properly protected.

The clays are usually of low fusibility, melting at the fusing point of cone 1 (1,150° C.), although a few do not fuse until cone 3 (1,190° C.), or in some instances even cone 6 (1,250° C.).

Space forbids a detailed discussion of the many localities, but a few may be referred to, while the results of tests of clays from each locality are given in tabulated form as an appendix to the text of this paper.

Winnipeg, Man.—Two types of clay are found here (Fig. 1):

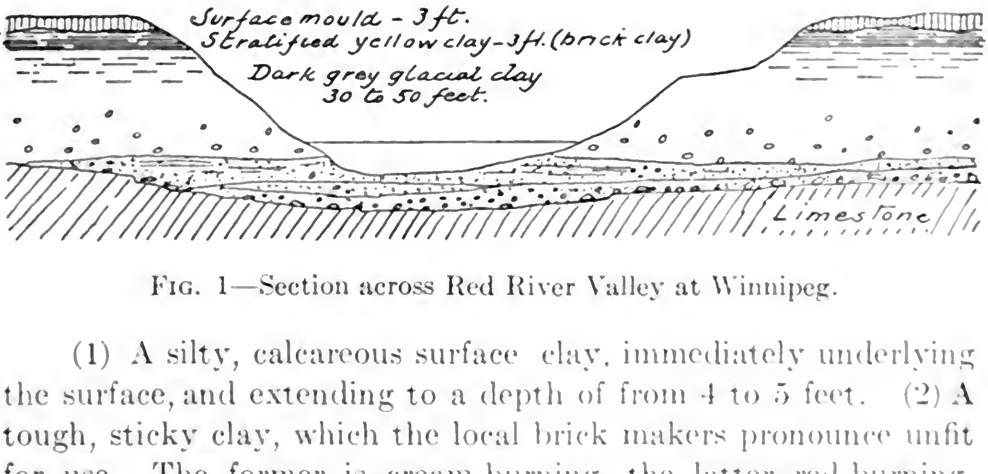


FIG. 1—Section across Red River Valley at Winnipeg.

(1) A silty, calcareous surface clay, immediately underlying the surface, and extending to a depth of from 4 to 5 feet. (2) A tough, sticky clay, which the local brick makers pronounce unfit for use. The former is cream-burning, the latter red-burning. The top clay is evidently a surface or flood-plain silt deposited by the Red and Assiniboine Rivers, while the bottom clay may be a lake deposit, laid down in the waters of Lake Agassiz which formerly covered this region.

The top clay is one of the most refractory of the surface clays found in the north-west. The temperature reached in the scove kilns is not less than cone 1, and in some cases may even reach cone 3. The clay fuses at cone 6.

The bottom clay is a very tough, sticky material, which is difficult to dry and burn. The brickmakers at Winnipeg assert that it is of no value, as when fired in their kilns it warps, cracks, and becomes porous. This is, no doubt, due in part to the fact that the surface clay used at this locality stands a higher heat. The extreme toughness and stickiness also interferes with the moulding. Difficulty was also encountered at the yard in drying this clay on the pallet racks, as it cracks badly. A sample pre-heated to 300° C. was still very plastic, but much easier to work up than the raw clay, and yet even after pre-heating to this temperature it would not stand rapid drying, although this treatment improved its drying qualities.

Clay Industry in the vicinity of Winnipeg.—A number of brick plants are in operation in the vicinity of Winnipeg, in all of which the calcareous surface clay is utilized, and as the deposit is rather shallow, and the output of brick large, a very extensive area has been worked over. Two yards have already been moved to other localities, and it is highly probable that at no distant date others will be compelled to follow suit.

All of the yards are engaged in the manufacture of common brick by either the soft mud or stiff mud process. At one yard, at least, hollow brick are also produced. The drying is done in open yards or on pallet racks, and burning in scove kilns.

Portage la Prairie, Man.—A somewhat extensive deposit of calcareous clay is found here in an abandoned channel of the Assiniboine River. The clay is nine feet thick and is underlain by sand and gravel. It burns buff, and is utilized for brick making.

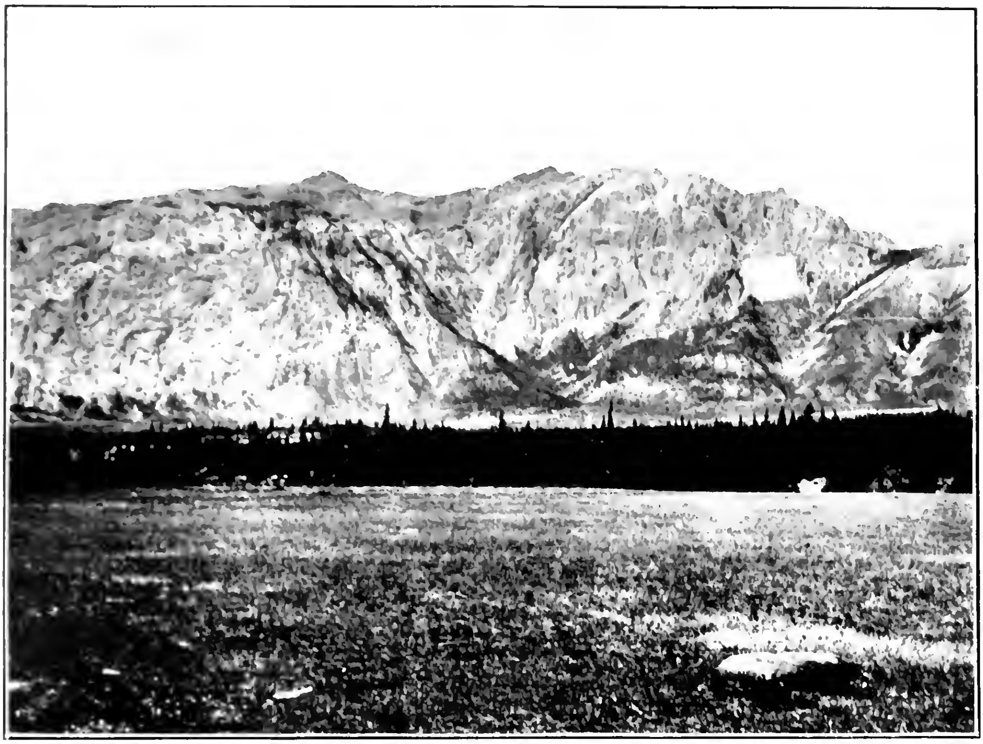
Several other deposits are worked in Manitoba, as at Virden, Hartney, Brandon, Somerset, Neepawa, etc.

In Saskatchewan the surface clays are utilized in the vicinity of Prince Albert for red brick, and also at Saskatoon.

Medicine Hat, Sask.—The surface formation here is typical of many other localities of the central plains. It shows a heavy deposit of silty or sandy clay, with occasional pebbly streaks, resting usually on the uneven surface of the Belly River shales, but sometimes separated from them by a layer of Pliocene gravels.

Scattered through these very silty clays are irregular patches of a tough dark clay, known as "gumbo," which is sometimes so hard and tough as to have the appearance of clay-shale.

Deposit of colluvial clay along line of Canadian Pacific Railway, at Field, B.C.



Folded limestone beds in Eastern front of Rocky Mts, Kananaskis, Alta. The flat track in the foreground is underlain by dark, gritty Cretaceous shales.

The Lethbridge Coal Co. (No. 6), Lethbridge, Alta.

At the several common yards in operation within the vicinity of Medicine Hat, only the silty clay is used, the gumbo being avoided for the reason that it is hard to dig, hard to mould, and does not burn well alone.

On the other hand, one cannot regard the silty clay as a satisfactory brick material, since it burns to a very porous brick, is very tender and cracks if exposed to the wind during drying. Moreover, some portions of the deposit are full of lime pebbles.

The silty surface clays are also worked at Prince Albert, Sask.; Red Deer, Alta.; Saskatoon, Sask., and other points.

Edmonton, Alta.—Two types of Pleistocene clay occur at this locality, viz., (1) flood-plain clays underlying the flat terrace bordering the Saskatchewan River, and (2) Glacial (?) Clays, underlying the upper level terrace on which Strathcona and Edmonton stand. The former are mostly utilized.

Flood-plain Clay.—This material, which is used by all four of the brick yards in operation at Edmonton, consists of alternating layers of sandy silty clay, and occasional pockets of gravel: in other words, it is a typical flood-plain deposit. So sandy is the material that one is surprised to find it employed for brick manufacture. Nevertheless it is utilized for both common soft mud, and dry-press face brick, the latter made from the less sandy portions of the deposit.

The thickness of these flood-plain clays cannot be exactly stated, but excavations at the brick yards show a maximum of not less than 9 or 10 feet, although in one pit bottom was struck at about 7 feet.

The supply, unfortunately, is sufficient to last for some time. The word "unfortunately" is used advisedly, because the clay does not make a very good brick, and a city the size of Edmonton should be constructed of better material. The tests given in the table published at the conclusion of this paper present some idea of the characters of these materials.

GLACIAL CLAYS.

Underlying the surface of the upper terrace there is a deposit of plastic clay, evidently of considerable extent, and far better quality than the flood-plain material. The main objection that a practical man would probably urge against it would be its high air shrinkage and toughness, but these could be overcome by the incorporation of a proportion of a more sandy clay.

At the time of our visit a good section of this clay was exposed in a deep trench on the University grounds near Strathcona. Only a small sample was collected, and this did not include about two feet of somewhat sandy clay immediately under the surface. It yielded a far better red brick than the clay used at the local brick yards.

Another deposit (1655 of table) of the same type of clay was obtained from N.E. corner, Section 15, Twp. 53, R. 25W., about three miles north of Edmonton. This clay belongs to the same formation as 1659. It worked up with 25% of water to a very smooth, plastic mass, whose average air shrinkage was 8·2% and average tensile strength 335 pounds per square inch. The air shrinkage is somewhat high, but the addition of 25% sand causes a considerable reduction in it.

For purposes of comparison the fire tests made on A, wet-moulded bricklets of the clay alone, and B, a wet-moulded bricklet of the clay with 25% sand added, are appended:

	A	B
Air shrinkage	8·2	6·5
Cone 010—		
Fire shrinkage	·15	0
Absorption	16·63	14·68
Colour	Light red	Light red
Cone 03—		
Fire shrinkage	2·4	2·3
Absorption	11·02	8·85
Colour	Red	Red
Cone 1—		
Fire shrinkage	Beyond vitrification	3·3
Absorption	......	1·5
Colour	......	Brown
Cone 5	Fused	

They were both steel hard and of good red colour at Cone 010.

The addition of the sand gave lower air and fire shrinkage and also reduced the absorption. The dry press made from the clay alone burned to a nice colour and body at Cone 05, but should preferably be burned to Cone 03. At the former cone its absorption was 17·42%, and at the latter 10·36%, as well as being steel hard. This clay also is better than that used for common brick by the yards at Edmonton. It might also be used for lining sewers if burned hard enough. The yards now in operation at Edmonton make not only a common brick, but also some dry press ones.

CRETACEOUS SHALES.

Shale of Cretaceous age and lower than the Laramie, which cannot be classed as wholly Cretaceous, are worked only in Manitoba. In that province they extend from the Pembina river at the International boundary, northwestward along the base of the Pembina, Riding, Duck, and Porcupine mountains. In Manitoba this system contains the following members in descending order: Dakota, Benton, Niobrara, Pierre.

The Dakota, or lowest member of the Cretaceous, resting unconformably on Devonian limestone, is composed of soft white or reddish sandstones, which are commonly interbanded with thin beds of shale. It occurs along the foot of the northern portion of the Manitoba escarpment, and appears to be exposed chiefly on the cut banks of streams, one of the best outcrops being on the Swan River some miles below the Canadian Northern railway crossing.

The Benton, which overlies the Dakota, is made up of very dark grey carbonaceous shale. This shale is evenly bedded and breaks down readily into small flakes. It is said to be 178 feet thick, and occurs along the foot of Duck and Riding mountains.

The Benton and Dakota shales were not examined, partly for the reason that they are at present more or less inaccessible, and no test of their qualities is on record.

The Niobrara formation conformably overlies, and is an upward extension of the Benton. It is prevailingly composed of grey calcareous shale, but toward the top of the formation a band of greyish limestone, often highly charged with pyrite, is generally encountered. Very characteristic exposures of these shales may be seen in the valleys of all the streams on the north side of Riding Mountain, from the Ochre to the Valley rivers. In the southern part of the province they may be seen on the Carman-Hartney section of the Canadian Northern railway between Leary and Cardinal, and on the Pembina river near the International Boundary.

NIOBRARA SHALES.

The shales of the Niobrara formation are used for brick-making only at one locality, viz., Leary, Man., a station on the Canadian Northern railway south-east of Winnipeg. They are here well exposed, as a bank has been opened at the base of a wooded hill, exposing about 30 feet of shale, capped with 6 feet of calcareous loam, which forms the first bench of the hill, to whose top the shale continues. Scattered through the shale are flakes of gypsum and concretions, some of the latter 2 to 3 feet in diameter and 1 foot thick.

The shale worked at Leary is red-burning and yields a good dry press brick; but the firing has to be carried on slowly to prevent cracking and black coring. The clay contains both gypsum and lime pebbles, and the latter if not ground fine enough cause trouble.

PIERRE SHALES.

The Pierre formation, composed almost wholly of shales, occupies the summits of all the higher land in the western portion of the Province of Manitoba and has a total thickness of about 800 feet.

The upper portion of the Pierre contains much hard light grey, fine-grained shale, while the lower part is made up of softer dark grey shale, containing crystals of selenite and nodules of clay ironstone.

No chemical analyses were made from our samples, but the following from a published source* may be quoted.

* Industrial value of the clays and shales of Manitoba, J. Walter Wells, Ottawa, Canada, 1905.

CHEMICAL ANALYSES OF PIERRE SHALES FROM MANITOBA.

	1	2	3
Moisture / Combined water } above 100° C.	6·06	6·78	8·25
Silica (SiO_2)	79·55	81·94	78·32
Alumina (Al_2O_3)	8·35	6·52	7·11
Ferric oxide (Fe_2O_3)	1·90	2·40	2·59
Lime (CaO	1·50	0·80	0·91
Magnesia (MgO)	1·02	0·93	1·28
Alkalis (Na_2O, K_2O)	1·17	1·30	1·11
Sulphur trioxide (SO_3)	......	0·16	0·05
Carbon dioxide (CO_2)	......	traces	traces
Organic matter, etc.	......	traces	0·29

(1) Compact, light, bluish grey, tough, smooth shale from Souris river, near Souris. Analyst, F. G. Wait, Department of Mines.

(2) Compact, light grey, fissile shale from south bank of Big Creek, northwest corner of Section 8, township 17, range 15 west. Analyst, M. F. Conner, Department of Mines.

(3) From bank of Assiniboine river 4 miles east of Virden. Similar to No. 2. Analyst, M. F. Connor.

The Pierre shales are but little used at the present time. When fresh the material is somewhat hard and forms a mass of rather low plasticity, but when weathered the product is highly plastic. As an example of the former I may quote in part, Mr. Keele's description of the shale from Birnie, Man:—

Birnie, Man.—"Streams issuing from the eastward-facing escarpment of Riding mountain, have cut down through a considerable thickness of Pierre shale. The Canadian Northern Railway between Neepawa and Dauphin is located on the terrace bordering the escarpment and approaches it closely at Birnie station. A sample was collected on the north bank of Big Creek at a point two miles west of Bernie station.

"The shale here is exposed in banks over 100 feet in height; it is generally uniform in character, light grey in colour, and contains bands of ironstone. The beds are much fissured, the fissures being coated with films of iron rust.

"The upper 30 feet of the deposit were sampled, but none of the ironstone nodules were included, as these could be thrown aside in mining. The deposit is easily accessible for working, and there is no overburden. The shale could be broken into cars and run down grade on a tramway to the railroad line."

The tests on this sample of unweathered shale (1623) are as follows:—It worked up with 37% of water to a feebly plastic mass, whose average air shrinkage was 4·9%. The average tensile strength was 113 pounds per square inch. No test was made to determine the rapid drying qualities.

Wet moulded bricklets behaved as below in the kiln tests:

Cone	Fire shrinkage	Absorption	Colour
010	2·45	28·73	Light red
03	4·00	24·45	Light red
1	5·00	19·50	Red
3	6·40	16·00	Brown

The clay does not show excessive fire shrinkage, but burns to a very porous body, and yet the bricklets have a good ring even at Cone 010. It is not steel hard at Cone 1, and, judging from tests made on similar material from another locality, it may stand Cone 5. To yield the best results this shale should be weathered before using; but this would be a rather long operation, as the shale seems to slake down very slowly under the weather.

Good results are often obtainable by using a mixture of Pierre shale and plastic surface clay. Acting on the above idea, a mixture (1633A) was made of 50% of 1634 and 50% Virden surface clay. This mixture worked up with 36% water to a mass of medium plasticity, with 4·2% air shrinkage, but a full sized brick would not stand rapid drying.

The burning tests show the effect on the surface clay in a reducing of the absorption:

Cone	Fire shrinkage	Absorption	Colour
010	2·7	27·45	Light red
03	·7	27·45	Red
1	7·0	7·17	Dark red
3	8·6	4·82	Dark red

The bricklets at Cone 03 had a good ring, and were very hard at 1.

The mixture at cone 1 had a lower fire shrinkage than 1633, and a higher one than 1644. The other properties were intermediate between 1633 and 1634. It makes a good dry press at Cone 03. It might also do for partition tile.

A mixture of three parts surface clay to one part shale (1633B) was also prepared. This mixture worked well when wet, and had an air shrinkage of 4·3 when dried.

In burning it behaved as follows:

Cone	Fire shrinkage	Absorption	Colour
010	0·7	26·00	Light red
03	0·7	25·00	Light red
1	10·3	0·32	Light brown

In general the addition of Pierre shale to surface clay causes it to dry quicker and overcomes the tendency toward checking in drying and reduces the air shrinkage.

When clay is used alone the bricks soften and become deformed at a temperature slightly above that of Cone 1; but the addition of shale helps to prolong the vitrification stage and prevent the sudden melting peculiar to calcareous clays making it possible to produce a ware having a dense body, which is difficult to obtain if the clay alone is used. In other words the shale acts as a "stiffener" to the clay.

Irvine, S. Dak.—In the hills forming the south side of the valley at Irvine, a number of natural cuts and gullies expose a series of beds of clays, sands and shales of Cretaceous (probably of Pierre) age. They consist of alternating beds of gypsiferous clays, sands and thinly laminated paper shales, the gypsiferous shales predominating in the upper half of the section and the sands in the lower. The whole series dips southeast at a low angle.

The gypsiferous shales form one bed at least 50 feet thick at the top of the section, and could be worked if necessary; and these are underlain by a bed of grey clay not less than 20 feet thick.

In the event of the utilization of these shales, the best results would be obtained by mixing in some of the sandy beds outcropping at the base of the hill. These, however, contain thin scattered layers or lenses of sandstone or cemented sand, which would have to be discarded in the mining.

BELLY RIVER FORMATION.

The rocks of this formation underlie a large area in Alberta and Saskatchewan, but there is usually such a heavy mantle of Pleistocene material that outcrops are scarce. They are consequently to be sought for only in the deeper valleys, although even there they may be discontinuous, partly because the surface of the bed rock is very uneven and the covering of later silts and clays may extend below the river level in places.

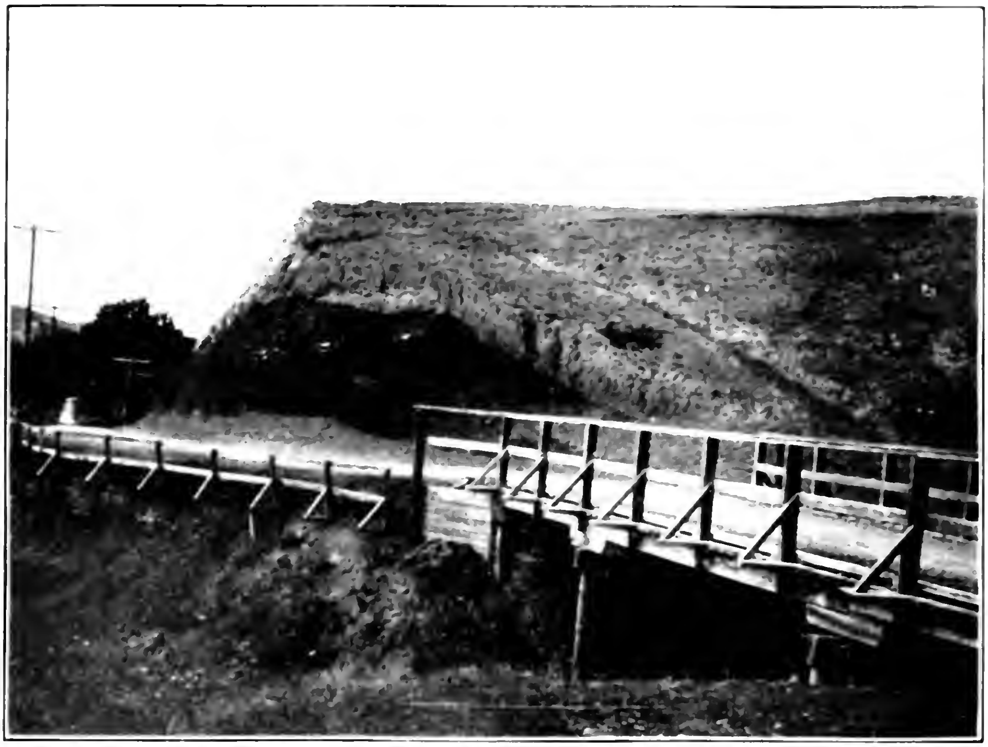
Where outcrops are lacking the character of the shales can in some instances be ascertained from coal mine workings or dug wells.

Dowling* in his report on the coal fields of Manitoba, etc., refers, of course, to exposure of coal only, but since the coals have shales associated with them, it may be well to allude to the areas of outcrop noted by him.

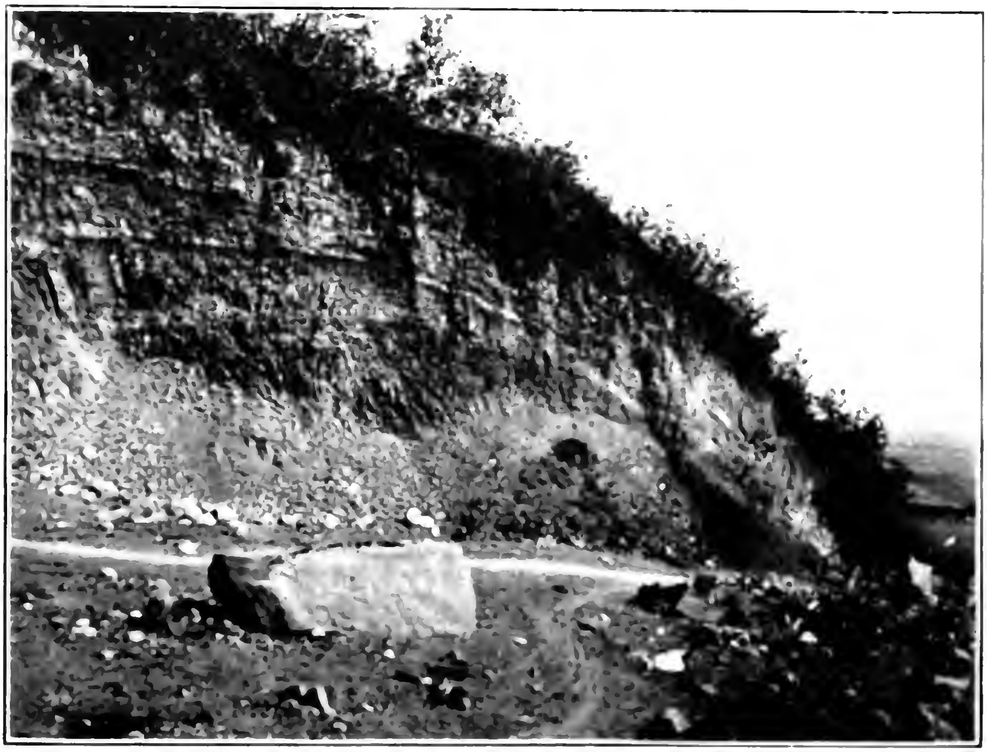
These coal beds are best exposed along the Belly River, near Lethbridge. South of Lethbridge there are a few on the Milk River ridge and on St. Mary river about six miles above its mouth. Again, the mouth of the Little Bow River at Stair, and for twenty-four miles below Medicine Hat, outcrops permit the tracing of a coal seam. He further mentions outcrops at the mouth of the Red Deer river. The formation is also found on the north side of the valley near Irvine Station, but to the eastward it either dips under the rocks of the plains or thins out.

To the westward of the area outlined on Dowling's map, the formation disappears beneath the trough which continues through McLeod northward past Calgary, and is said to reappear in several narrow bands in the foothills to the west of Calgary and in the Peace River country. Dowling states, "In the strip which runs through the foothills large portions are not prospected, but for one area at least we have more details." This comprises the

* Can. Geol. Surv., Paper No. 1035.



Bed of dark grey shale overlain by drift on roadside near highway bridge, Lethbridge, Alta.



Beds of alternating shale and sandstone on property of Calgary Pressed Brick & Sandstone Co., Brickburn, Alta.

Silts, clays and cross-bedded sands,—probably Pleistocene—
Medicine Hat, Alta.

foothills south of the main line of the Canadian Pacific railway, as far as Highwood River. On the Stoney reserve, south of Morley station, is a 6 foot seam in this formation. Exposures of the formation are also referred to on Jumping pond and Elbow rivers, and on the south branch of Sheep Creek. Near Kananaskis station the Rocky Mountain outer range overrides these beds.

In the Peace River country* two areas of the Belly River formation are known. One of these is in Alberta, reaching up the Smoky river to the valley of Peace river, and one in British Columbia, near the Peace River canon. The area over which the Belly River formation occurs is about 25,000 square miles. At the persent time the Belly River shales are worked only in the region about Medicine Hat, but promising exposures also occur at Lethbridge and on Milk Creek south-west of Pincher.

Lethbridge, Alta.—A number of shale beds were penetrated in sinking the shafts of the Lethbridge Coal Company no th of the town, but the materials passed through were all either very carbonaceous or gritty, and no samples were tested.

Along the Belly river at Lethbridge there are some outcrops of shale, but they are near the river level, and lie under a heavy overburden of Pleistocene silts and gravelly sands or till.

A few feet south of the eastern end of the waggon-bridge across the Belly river is an outcrop of shale of most deceptive character. This material (1666) in its raw conditions appears to be carbonaceous and gritty, but mixes up to a very plastic mass. It is well worth utilizing, is easily accessible, and far superior to the surface clay used for making common brick at Lethbridge. The only objection to its use is a somewhat heavy overburden, but this could be easily removed.

Milk Creek, Alta.—Milk Creek, a tributary of the Old Man river, lies south-west of Pincher. The road to the Beaver Creek valley crosses it about 10 miles from Pincher, and at this point are a number of exposures of shales and sandstones, some of the beds indicating very strong folding, and many showing a nearly vertical dip. Just before reaching the bridge across Milk Creek the thinly laminated shales, outcropping on both sides of the

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* Dowling, C. C., quotes from Report of Progress, 1875-6, pp. 6, 53; Ibid, 1879-80, pp. 117, 119, 134, 136B.
Report of Progress, 1882-1884, pp. 25-39 M.

stream, contain much carbonaceous matter and sandstone layers. A somewhat plastic shale, however, outcrops under or close to the bridge over Milk creek, and is typical of several shale outcrops near there. It burns to a good red brick body.

About 500 feet up stream from the bridge is a long steep bank exposing shales and sandstones of vertical dip, and striking across the stream. The shales are decomposed to a depth of a few feet from the surface. One bed of shale (1669) is about 100 feet thick. It is slightly calcareous, very plastic and gritty. Even the small bricklets checked in air drying, but the addition of 1% of salt stopped this. The shale, however, shows a low fire shrinkage and fairly low absorption, and does not begin to fuse until Cone 5. It may be possibly utilized for hollow-blocks, fire-proofing, or perhaps even sewer pipe, although there is some doubt whether it is sufficiently plastic for this purpose.

It makes a good dry-press, and is nearly steel hard at cone 05. The surface showed small cracks, and if used for this purpose the clay might require pre-heating.

Medicine Hat, Alta., district.—Some of the best exposures of the Belly River formation are found along the Saskatchewan and tributary valleys in the vicinity of Medicine Hat.

McConnell,* in speaking of the district, says:—"The Saskatchewan at Medicine Hat enters and traverses for some distance one of those drift-filled depressions, which so constantly interrupt the sections on all the principal streams. West of Medicine Hat the Saskatchewan is somewhat closely confined to a narrow valley, by rocky banks, but east of that point it becomes much more tortuous and continues so until it crosses the pre-glacial hollow.

"The deposits in this basin are partly glacial and partly pre-glacial. The latter are pebble conglomerates, coarse ferruginous sands with small pebbles, silts and sands. They are probably of Pliocene (Tertiary) age.

"The glacial deposits consist of light yellowish boulder-clay overlaid in some places by thick sandy beds.

"The rocks of the Belly River series disappear below the Pliocene at Medicine Hat, and reappear about seven miles farther

* Can. Geol. Surv., Rept. 1885, C, p. 57C.

down. The exposure consists of dark arenaceous shales overlying greyish sands and sandstones, and underlying unconformably the sands and gravels of the Pliocene. A few miles further down, the same beds enclose a small coal seam, which occurs at the same horizon and is probably a continuation of the seam mined above Medicine Hat. It is seen at several places between Medicine Hat and Drowning Man's Ford."

"A promising exposure occurs about one mile north of the southern boundary of T. 16, R. 5, W of 3rd principal meridian. Between here and Drowning Man's Ford the Belly River rocks are often well exposed along the river.

"The river bends east from Drowning Man's Ford, and passes through a deep canon, containing fine exposures of the upper part of the Belly River series and exhibiting pure clays and sands with all gradations between the two.

"They are extremely irregular and no section measured at one place would be applicable anywhere else."

The Belly River series* which underlies the Pierre is represented by its light-coloured upper division, which is distributed over a large area in the north-western and south-western part of the district. It is well shown in the cañon-like part of the Saskatchewan between Medicine Hat and the mouth of the Red Deer, where almost complete sections can be obtained, and also in the valleys of Milk River and Many Berries Creek, at Bull's Head plateau, Ross Creek and numerous other places along its eastern boundary.

In the time at our disposal it was possible to examine some of the sections only in the vicinity of Medicine Hat.

Red Cliff.—About six miles up the Saskatchewan river from Medicine Hat a fine section is obtained in a narrow coulee leading from the top of the plain at the works of the Red Cliff Brick Company down to the river. The Company has opened up a large pit about 100 feet below the plain level, and the general section from the top of this excavation down to the river level is as follows:

Shales with some sandstones	50 feet.
Dark chocolate clay, cracks in drying	3 "

* l.c. P. 63c.

Alternating shales, silts and some lignite seams	30	feet
Lignite	5	"
Sandy shales	15	"
Lignite	4-5	"
Carbonaceous shale	2	"
To river level .....(concealed)	50	"

It is not known how far each of the shale and sandstone beds mentioned in this section, extends horizontally, but they are all of undoubted lense-like character, and on the opposite side of the river at Anslee's mine the section is distinctly different, but this will be referred to later.

Returning to the clay pit of the Red Cliff Brick Company, the section there is made up of grey, green, brown and blackish shales of varying texture, interbedded with sandy streaks or sandstone layers of varying thickness. Some of the shales are very smooth; others contain sandy streaks and even thin laminæ of coal. The run of the bank, excluding the sandstone beds, is used for making common wire-cut brick, and a layer about two-thirds up the face is used for dry-press. At the bottom of the bank is a dark-coloured clay shale, which checks in drying if used alone.

In order to determine the qualities of these, three samples were tested and the details of these (1686, 1687, 1688) are given in the table. The run of the bank gives a mixture of good plasticity, which burns to a red body, but causes some difficulty in drying. The main use of this shale is for brick manufacture. Near the top of the bank, however, there occurs a layer (1686) which makes a good red dry-press brick.

Coleridge, Alta.—This station, formerly called Dunmore, is located on the main line of the Canadian Pacific railway, about six miles north-east of Medicine Hat. The clay pits of the Alberta Clay Products Company are located on the west side of a ridge, overlooking the valley of Bullshead Creek, and about one and a half miles south-west of Coleridge. The ridge rises rather steeply from the bottom land, and shows few natural outcrops until near the top, where sandstone ledges appear. The shales are more or less covered by wash, and later silts and gravels. On a spur of the ridge a bank was being opened in the summer of 1910. At this point there was in places not less than fifteen feet of stripping. The bank had not been opened to any great extent, but from the excavation made, together with limited exposures in a shallow coulee cutting through the deposit, we were able to form some idea of the mode of occurrence. From the data thus obtained one finds that the general arrangement of the beds is lenticular and consists of clay shales of varying degrees of siliceousness, smoothness and colour, interbedded with some soft sandstones. This means then that care must be exercised in working the deposit, to prevent the mixing of shales of widely different character.

It is somewhat difficult to describe the arrangement of the clays in the bank, but the following may serve:

On the south side of the coulee, near the base of the bank is a tough, brownish clay, known as sewer-pipe clay. The greatest thickness of this is about ten feet, and it can be traced for about thirty feet to the left side of the entrance to a short drift. Overlying the sewer-pipe clay is a stiff blue clay, and on top of this is sand. The higher portion of the section was not uncovered. The blue clay is said to crack in air drying. Both the blue clay and the sand appear at a somewhat lower level in a trench on the north side of the coulee.

Another lens of clay, called pressed-brick clay, outcrops on the south side of the coulee, between the loading platform and the railroad track, and it is possible that the sewer-pipe clay grades into it, since they adjoin each other at the same level, but a short drift had been dug out on the line of contact. At the east end of the bank, by the powder house, a buff clay (No. 1693) outcrops, but its horizontal extent is not known, although it may pass under the fire clay outcropping nearer the coulee. The latter (1692) is a black, coarse-textured clay with numerous fragments of plant remains, and having a thickness of about six feet. It extends across the face of the hill from near the powder house to the coulee, and there seem to be traces of it on the other side, above where the pipe clay is being dug. Overlying the fire clay is a lighter coloured sandy clay, which in turn is capped by a thin bed of soft sandstone. It is said that borings which have been made on the property have disclosed the presence of much clay, and this is no doubt true, but the lenticular character of the beds, and consequent necessary sorting will preclude the possibility of mining by any such cheap method as steam shovelling. The overburden will also increase as the workings extend into the hill.

Tests of several shales from this bank are given in the table at the end of the paper. They are mostly red-burning, and all fuse at a moderately low cone, except one bed of so-called fire clay which stands Cone 12. These shales are now being utilized by the Alberta Clay Products Company of Medicine Hat, for making red pressed brick and sewer pipe. The most refractory of the shales can be employed for boiler setting brick.

South bank of Saskatchewan, west of Medicine Hat.—An examination was made of the shale deposits outcropping between Medicine Hat and Anslee's mine opposite Red Cliff. About one and a half miles west of town, a deep coulee shows an outcrop of lignite, a few feet above the river level.

Shales occur above and below the coal, but they are mostly sandy and it is doubtful if they extend very far above the lignite, as the float on the sides of the coulee indicates an abundance of sandstone. Immediately above the lignite is a two-foot layer of clay shale, which could be easily mined with the coal. Although it had a greasy look so frequently seen in many clays running high in colloidal matter, still a small sample (1695) was taken for testing. Its properties are as follows:

The shale burned to a nice red colour, but had a rather high fire shrinkage. At the same time it burned to a fairly dense body at Cone 03, and a very dense one at Cone 1. Its fusion point was not determined, but it probably does not exceed Cone 3.

This is a good brick shale, if the large bricks will dry without cracking, but it is of no value unless mined in connection with the lignite.

Anslee's mine.—At Wm. Anslee's mine, there is an incline running from the top of the cliff down to the river level, a difference in elevation of about 250 feet.

A fine section is exposed along this, and although it is directly opposite the Red Cliff one, already referred to, differs from it to a marked degree. Indeed careful search failed to reveal any series of beds like those at Red Cliff, the only similar deposit being one about twenty feet below the top of the incline. This is a yellow and grey mottled clay similar to the deposit used for dry-press brick at Red Cliff. The lens is of limited size and grades into a brownish clay shale resembling the "sewer pipe" clay mined near Coleridge.

The remainder of the section down the incline to the first lignite seam, consists chiefly of sandy shales and sands, but just above the lignite is a two-foot layer of light clay, and under this same (upper) lignite seam is a reddish clay shale. The latter could only be worked by under ground methods, and is probably not of sufficiently high quality to warrant the expense.

The only sample tested from the entire section was the mottled clay from near the top of the incline. This material (1696) was found to be a very plastic, smooth, non-calcareous shale, which worked up with 31 per cent of water, and in the test bricklets showed a rather high air shrinkage, viz., 10·8 per cent. Further tests are given in the table.

LARAMIE FORMATION.

The Laramie formation proper underlies a small triangular area in southern Manitoba, in the Turtle Mountain region. Farther west a second but much larger triangular area is found in southern Saskatchewan. The base of this triangle forms the southern boundary of this province as far west as the Wood Mountain district, which is included in it. From the apex of the triangle a narrow belt extends northwestward to a little beyond the main line of the Canadian Pacific railway west of Moosejaw. This area it will be seen includes the Souris coal-field and the Dirt Hills.

Detached areas are found west of this, where the Laramie formation occupies the summits of some of the plateaux, and portions of elevations such as the Cypress Hills.

Shales of Souris Coal-Field.—The Souris field lies in southern Saskatchewan, just north of the international boundary, and east and west of the Canadian Pacific railway line from Moosejaw to Portal.

The exact areal extent of the field is not known, because there are so few exposures, and a heavy surface covering of boulder clay, which extends northward through the Moose Mountains and beyond the Assiniboine River.

The eastern outcrop of the coal rocks is concealed by it, but they are known to extend at least as far as the mouth of Moose Mountain Creek. Associated with the coal seams are beds of clay shale, sandy clay, and sandstone, but since they are not always persistent, there may be some question as to the value of considering the stratigraphic details of the field.

It may be briefly stated, nevertheless, that the coals, which are of Laramie age are divided by Dowling into an upper, middle and lower horizon.

The upper horizon generally carries a four-foot seam that is fairly continuous, but in places thins out or is joined by seams of the middle horizon to form a seven-foot seam. The coal seams are separated by deposits of sandstone, clay and shale of varying thickness and areal distribution. The upper horizon bas heen prospected at several points in the vicinity of Estevan.

The middle horizon is found exposed along the north side of the Souris valley.

The lower horizon is the most important in the district.

Dowling in his report gives a number of sections, some of which indicate a sufficient thickness of clay to be worth working.

The shales were examined and samples collected at several points in the Souris field as follows:

Estevan.—About one and a half miles east of the town excavations have been made in the east slope of a broad coulee, by the Estevan Coal and Brick Company. The section there shows:

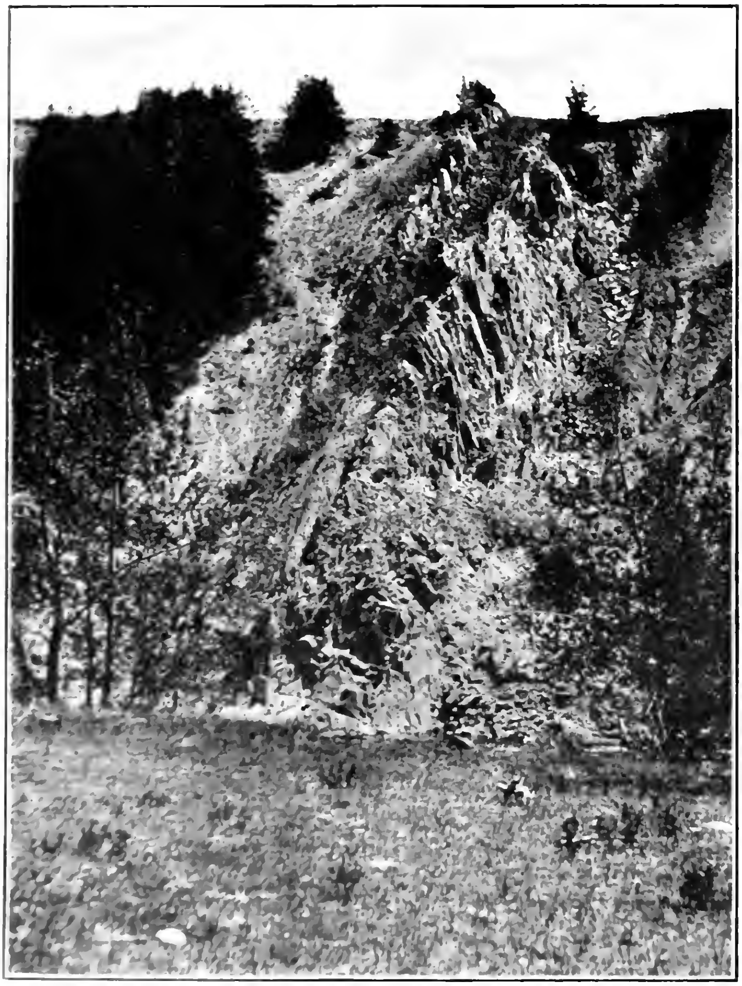
Boulder clay, with shale fragments in lower portion	10 to 20 ft.
Lignite.	8 ft.
Parting clay.	2 ft. to 2 ft. 6 in.
Lignite.	8 in. to 2 ft.
Blue clay shale	30 to 40 ft.

Upper 15 feet smooth, but lower portion quite sandy.

The top clay which is a calcareous, glacial clay with scattered stones, pebbles and boulders, is worked as an open pit. The large stones are thrown out in the pit, but the smaller ones are crushed in a rolls. A sample of the material thus crushed was taken for laboratory test.

Shale and clay deposits on the banks of the Saskatchewan River, Alta.
Clay pit of the Red Cliff Brick Co. in foreground.

Outcrop of sandstone in Souris Valley near Pinto, Sask.



Vertical beds of partly decomposed shale near bridge on eastern bank of Milk River, Alta.

The surface clay at this locality is very calcareous and makes a common cream-coloured brick.

Of the clay shale underlying the lower lignite seam, only the upper nine feet were being worked at the time of our visit, but the company proposes to strip off first the top clay and lignite, and then use the parting clay, lower thin lignite and lower blue clay shale altogether.

The nine feet referred to above were being removed by drift and chamber mining in the summer of 1910.

The under clay is very plastic and sticky when wet, and cracks in drying unless pre-heated. It is utilized for dry-press brick. The lignite obtained at the mine near the works is used for fuel.

Pinto.—At Pinto Station, the Pinto Coal and Brick Company has driven a short slope about 300 feet long, which at its lower end meets a bed of lignite belonging presumably to the upper horizon. Overlying this is a buff clay shale (1641), about five feet thick, which we sampled in the mine, and higher up, but not immediately overlying it is a softer reddish shale (1642). Another shale (1643) underlies the lignite.

The measures here lie horizontally or nearly so, and these beds should outcrop in the Souris Valley a few hundred feet to the north, but since the clay shale and sandstone beds are not apparently as continuous as the coal beds, there may be some doubt whether they extend that far.

The Souris River has here cut a fine trench in the plain, but while the sandstone ledges stand out here and there on the valley sides in some prominence, the softer layers such as clay and shale have mellowed down and are more or less completely concealed.

The shale over the coal is red-burning and makes a good dry-press brick, while that under the coal burns to a good red body but cracks badly in drying.

No general statement can be made regarding the shales found in the Souris field, but the results obtained in our laboratory tests warrant the hope that other good shales may be found.

The field should be carefully prospected, for the shales or clay if suitable can, in most instances, be cheaply mined or excavated, and moreover they are well located with references to lines of transportation. Fuel, also, is plentiful and cheap. The growing cities of Moosejaw and Regina form a nearby market.

Dirt Hills.—The Dirt Hills form an isolated elevation rising from the plains about twenty three miles south of Drinkwater, and about thirty miles south of Moosejaw. They have received some notice because of the coal seams which were known to occur in them, and were made the subject of a report by Dr. Bell* at an earlier date.

The strata in this locality appear to be about horizontal, but in the great masses detached by the landslides they are tilted up to various angles as high as 45°, the slope being to the southwestward. The large surfaces of bare and often muddy clay, which are here exposed, contrasting with the grassy or gravelly prairies, have probably given rise to the name which these hills bear.

It is in these Laramie beds, exposed in the landslide masses on the north side of the hills, that one finds some of the most refractory clays thus far discovered in western Canada.

The clays which were examined occur in Section 28, township 12, range XXIV, west of the 2nd Mer., and form a series of knolls at the base of the hills. All the beds appear to dip westward, the knolls having a steep eastern face and a gentle western slope. They can be described as a series of white and greyish-white sandy clays, bluish and purplish clays, brownish siliceous clay shale, and gypsiferous shales. On account of their great importance, they may be referred to in some detail.

At the west side of a ridge, projecting out from the hills, is a spur or knoll containing a series of alternating red and brown siliceous shales, which have been referred to by some as sewer-pipe clays. The individual beds of this series differ somewhat in their sandiness, and if used the entire series should be mixed together. A few scattered sandstone layers are present but these are soft and could be easily crushed up.

Overlying these siliceous clays and separating them from the first knoll to the west, is a series of soft sandstone beds, containing large scattered concretions. These beds should not be mixed in with the shales underlying them.

The following tests represent the character of the "sewer pipe" clays (1646), the sample being taken by making a trench across the complete section of the beds.

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* Report on Progress, Geol. Surv. Can., 1873–74, p. 76.

The sample thus obtained, when ground and tempered with water, formed a stiff plastic mass which was hard to work and cracked badly in air drying.

As the clay was useless in the natural state, a portion of the sample was pre-heated to a temperature of 500° C. Under this treatment the clay changed to a red colour and became granular in texture, but retained sufficient plasticity to be wet moulded. It also stood fast drying, and the air shrinkage was 3·3 per cent. The burning tests of wet-moulded bricklets were as follows:

Cone	Fire shrinkage	Absorption	Colour
010	1·7	9·7	Light red
03	9·3	5·5	Red
1	13·3	Vitrified	Brown

This clay has too high a fire shrinkage, but it might be useful to mix with some of the more refractory clays of the locality in order to produce vitrified wares at lower temperatures.

The hill west of the sewer-pipe beds shows heavy beds of grey and greyish-white sandy clay, and brownish-grey clay, the two sets being separated by a thin layer of lignite. The brownish-grey clay (1647) forms a bed about twenty feet thick in the lower half of the section. It is a plastic clay, containing much fine grit, and worked up with 30 per cent of water. Small pieces dried slowly without cracking, but large ones crack badly in rapid drying. The average air shrinkage was 8·5 per cent, and the average tensile strength 334 pounds per square inch.

The wet-moulded bricks yielded the following results on burning:

Cone	Fire shrinkage	Absorption	Colour
010	·2	16·28	Pale red
03	4·4	7·52	Light red
1	5·4	4·78	Brown
3	5·3	4·39	Brown

The air shrinkage is somewhat high, but in actual working it would be lower. The fire shrinkage at Cone 1 is not excessive. The absorption at this cone is also low. The clay burned steel hard at Cone 03, but if fired too rapidly may develop a black core at Cone 1. It burned to a good hard body and stands Cone 3. The clay gave a dry-press bricklet of fair colour and ring at Cone 05, but if moulded by this method should probably be burned to Cone 03.

The absorption at Cone 05 was 18·62, and at Cone 03, it was 10·93, with the bricklet steel hard.

Overlying the preceding is a grey and white sandy clay (1648) containing lenses of white clay (1649). Where the clay is exposed it would hardly pay to separate these lenses, but if they occur in greater quantity in other parts of the deposit, it would be worth doing so. On this account we not only made a test of the run of the deposit, including the white clay, but also of the latter alone. The run of the bank (1648), although containing considerable sand, worked up with 27 per cent of water to a mass of good plasticity, and one which caused no difficulty in moulding.

The average air shrinkage was 6·1 per cent and a full-sized brick stood fast drying. The average tensile strength was 123 pounds per square inch.

The clay appears to contain a noticeable amount of soluble salts, which collected on the corners and edges of the brick in drying, and caused a slight enamel on those parts, even at Cone 03.

Wet-moulded bricklets yielded the following results:

Cone	Fire shrinkage	Absorption	Colour
010	0	18·58	Whitish
03	2·7	15·41	"
1	3·3	13·19	"
5	2·7	10·70	"
9	3·3	9·81	"
32	Fused		

Small black iron specks began to appear at Cone 1. The clay has a low fire shrinkage, and the absorption above Cone 010 is not excessive. It burned steel hard at Cone 1.

This clay can be classed as a fire clay, and represents the most refractory one found by us in western Canada. A dry-press bricklet burned to Cone 1, was not steel hard, with an absorption of 17·50 per cent.

Since the clay is rather loose in texture, it was put through a washing test and 45 per cent of washed product obtained. The latter (1651) showed an average air shrinkage of 8·5 per cent. Burned to Cone 5, its fire shrinkage was 9·7 per cent, absorption 7·11 per cent, and colour light creamy white. It was also steel hard but showed some small cracks. At Cone 9, the fire shrinkage was 11·3 per cent, absorption 3·7 per cent, and colour greyish-white.

Since there is a large quantity of this material it might pay to wash it and use it in pottery bodies. Some difficulty would be encountered in getting sufficient water, but the springs on the neighboring slopes could be drawn upon for this purpose.

The white clay (1649) forming lenses in 1648, although appearing smooth, nevertheless contains considerable fine grit, and an appreciable quantity of soluble salts, which came out on the edges as needle-shaped crystals in drying. It worked up with 30 per cent of water to a mass of good plasticity, whose average air shrinkage was 7·7 per cent.

On burning the wet-moulded bricklets behaved as below:

Cone	Fire shrinkage	Absorption	Colour
010	·35	16·74	Creamy white
03	3·7	10·34	"
1	5·3	7·67	"
5	6·6	4·67	"
9	6·6	2·60	"
31	Fused		

The clay burned nearly steel hard at Cone 010, and gave a pretty dense body at Cone 5. Small black iron specks appeared at Cone 1. This is a dense-burning fire clay, and it is unfortunate that it does not occur in larger quantities.

The grey clay (1650) described here, overlies 1648. It does not appear in the steep southern escarpment of the hills, but shows on the gentle north slope. Like 1648 it mixed up to a mass of good plasticity, whose average air shrinkage was 7·8 per cent.

Wet-moulded bricklets were tested as follows:

Cone	Fire shrinkage	Absorption	Colour
010	1·	16·76	Cream white
03	3·6	11·60	"
1	6·0	8·23	"
5	6·6	4·37	"
9	8·4	2·25	"
32	Fused		

The clay burned nearly steel hard at Cone 010, and thoroughly so at Cone 03. Small black specks appeared at Cone 010. This clay closely resembles 1649, but has a slightly higher fire shrinkage. It is a good dense-burning fire clay and well worth working.

Owing to the fact that 1648 cracked to such a degree in drying it was decided to try a mixture of equal parts of 1646, 1647 and 1648. This (1651) when tempered with 32 per cent of water was very plastic and small test pieces dried without checking. The air shrinkage was 8 per cent.

The wet-moulded bricklets fired as follows:

Cone	Fire shrinkage	Absorption	Colour
010	1·0	14·16	Light red
03	3·3	8·00	Red
1	4·3	5·33	Brown

This mixture burned to a steel hard body at Cone 010, at which temperature it would probably make good common brick either by the soft-mud or stiff-mud process. At Cone 1 the fire shrinkage is rather high, and the body not burned quite dense enough for sewer pipe, but would probably become more vitrified at Cone 2. The mixture makes an excellent dry-press brick of good colour and steel hard at Cone 05, with an absorption of 13·75 per cent.

Clays and shales similar to those seen at the Dirt Hills occur rather widespread in the western part of the state of North Dakota,* and are worked at two points, Hebron and Dickinson, on the Northern Pacific railway.

The section at Dickinson shows eight feet of almost white fire clay and about two feet of fine plastic pottery clay, underlying which is six feet of a semi-refractory grey clay. These beds rest partially on a thick lens of greyish white sandy clay, almost identical in composition with No. 1648.

There is a layer of hardened yellowish clay found generally overlying the white clays in the vicinity of Dickinson, which is absent in the area examined at the Dirt Hills. This hard clay is useful in the manufacture of fire bricks, as when coarsely ground it serves as "grog" for the plastic clays. A grey and yellow ferruginous shale or clay, similar to 1646, underlies the fire clays and sands and is here used for red dry-press bricks or for mixing with the semi-refractory grey clay to produce a spotted facing brick.

The dry-press process only is used at these works, fire brick and facing brick alike being made by this method. The fire brick which are made in eight and nine inch sizes are often shipped in large quantities to the neighboring part of Canada, the price obtained being $25.00 and $28.00 per thousand f.o.b. Both the Hebron and Dickinson plants send buff and spotted facing brick into Canada.

Edmonton formation.—This formation underlies a belt of varying width extending from the international boundary northward through the centre of the Province of Alberta.

In Alberta it is divided by Dowling into two parts, 1, a coal-bearing member known as the Edmonton and likely to be the more productive of shales, and 2, a heavy sandstone formation known as the Paskapoo. The first forms a trough, which is filled along its center by the latter. This trough widens toward the north, and also flattens, exposing a larger area of the Edmonton series than in the southern part.

Considerable attention has been given to the coal seams in the reports of Tyrrell † and Dowling ‡ but practically nothing

* The note on these is supplied by J. Keele.
† Annual Report, Geol. Surv. Can., 1886, Vol. 11.
‡ Can. Geol. Surv. No. 1035.

is said regarding the character of the associated shales. This is not unnatural since their economic value had not been considered. However, it is reasonable to suppose that at many points where the coal outcrops mentioned by these authors, occur, there the shales may be exposed also. This would be mainly in the Edmonton series.

The shales are found with the coal seams in the vicinity of Edmonton, and also up the Saskatchewan River south of there, as well as westward in the vicinity of Pembina. Shale exposures should also be looked for on the Red Deer River, within the limits of the area underlain by the formation, and on the Bow River near Crowfoot Crossing. A narrow belt of the Edmonton formation occurs along the foothills, and passes west of Cowley on the Crow's Nest branch, and west of Cochrane on the main line of the Canadian Pacific.

Cowley.—The most southern deposit of Edmonton shales visited was west of Jameson's mine south of Cowley, and six miles north-west of Pincher. The mine is located on the south fork of the Old Man River, in Sec. 27, Tnp. 6, R. 1 W.

Along the bank of the river the visible exposure consist of alternating beds of sandstones and sandy shales, dipping northwest about twenty degrees. At the coal mine, the beds turn up suddenly along a fault line, and the coal is badly crushed. Overlying the coal, which is bituminous, there is a fifteen-foot bed of clay, which has also been disturbed somewhat by the faulting, for coal fragments are contained in it near the contact of the two.

It has been commonly supposed that this material was a fire clay, but the tests (1675) given below disprove this. The clay burned to a good colour at the lower cones and is steel hard at Cone 03. Above this cone the colour becomes poor. The position of the clay would make it rather expensive to mine, and operations would require to be carried on in connection with the coal extraction. The clay might be serviceable for sewer pipe, but for this purpose is not as desirable as the material located on Milk Creek. It is not a fire clay. Pressed brick could probably also be made from it.

Lundbreck to Bermis.—East of the front range of the Rockies, the country is broken by a series of hills and ridges, whose axes lie more or less parallel with the mountains. These ridges contain

Clay and lignite beds at Estevan, Sask.
Pit of the Estevan Brick and Coal Co.

a series of folded shale and sandstone beds, which dip at a varying angle, as in the case of those between Lundbreck and Bermis. The beds are well exposed in a series of cuts along the Crow's Nest Pass branch of the Canadian Pacific railway, beginning about two miles west of Lundbreck, the last being about one half mile east of Bermis. In most of the cuts the shale beds are lenticular, and rarely over a few feet in thickness, but if they were refractory it would be possible to work them as narrow cuts. With this in mind, samples were taken from the most promising looking exposures but none of the samples proved to be fire clays. All were red-burning. The best exposure observed was a dark shale on the bank of the Old Man River, one mile west of Lundbreck. The width of the outcrop is over fifty feet and there is no overburden. This shale may be suitable for paving brick.

Edmonton.—Here the Saskatchewan River has cut a trench about 160 feet deep through the strata of the Edmonton formation. This would afford an excellent section were it not for the numerous landslides which conceal the beds on the valley sides. The shales and sandstones are found above and below the coal seams, and at a higher horizon than the coal. There may also occur here beds of massive shale. These shales associated with the coal are often carbonaceous in their character, and few of them were tested. One, representing a two-foot seam under the coal at the Ritchie mine, stood Cone 13 without fusing, but the bed is too thin to work, and moreover the shale would require to be pre-heated as it cracks so badly in drying.

One of the heaviest series of shale beds is that on the property of the Western Clays Company, which owns eighteen acres near Strathcona, lying between the waggon-road from Edmonton to Strathcona, and the Edmonton, Yukon and Pacific Railway.

The natural outcrops occur along the line of this road below the Twin City mines, at the latter, and between them and the Western Clays Company's property. These several outcrops show a variety of shales. In most of the outcrops exposed before reaching the Twin City coal mine, there is little scope for development, as the highway is too close to the railway. Shortly before reaching the Twin City mine however, the two roads diverge, and opportunities for development consequently are improved. The shales on the property of the Western Clays Company, Ltd., are prevailingly grey with brownish or yellowish streaks and occasional small iron crusts. All the beds weather down to a plastic clay. There is no doubt that these shale beds are at a higher horizon than the coal in the Twin City mine, but their exact thickness is not known, as none of the borings sunk went deeper than twenty-three feet.

On the opposite side of the small valley in which these shales outcrop, there appears to be a heavy drift mantle, and it is said that the company prospected in this locality without result. If the beds continue on the other side of the valley, they must lie at a slightly higher level, as the formation rises in that direction.

It is asserted that tests made of these shales in England have proven their value for paving brick and sewer pipe. The tests of these shales, Nos. 1656, 1657 and 1658 are given in the table. A serious drawback is their high air shrinkage.

Entwistle, Alta.—A heavy series of shale beds occurs on the property of the Pembina Coal Company, Ltd., at Entwistle, Alta. We did not have time to visit this locality, but the section (Fig. 2 supplied by Mr. C. C. Richards, Superintendent) shows the position and thickness of the beds, and also the location of those from which samples were tested. These samples were taken by Richards in accordance with our instructions. The tests are given in the table (No. 1660, 1661, 1661A, 1661B and 1662).

These shales are among some of the best seen in western Canada. No. 1662 seems adapted not only to the manufacture of common brick, but might probably be serviceable for paving brick, sewer pipe or hollow brick. No. 1663 fuses at a lower cone and worked dry-press.

Under the coal bed at Entwistle is a very plastic sticky clay (1661), which cracks badly in air drying of even small bricklets, but it is one of the most refractory clays tested from the Edmonton region. In order to improve the working of this clay it was tested under three different conditions as follows:

1661. Untreated clay. Very plastic, sticky, hard to work, could be dried without cracking only in moist atmosphere.

1661A. Clay, with 1 per cent. common salt added, worked up much better, and did not crack in air drying.

1661B. Pre-heated to 350°C, still cracked on air drying.

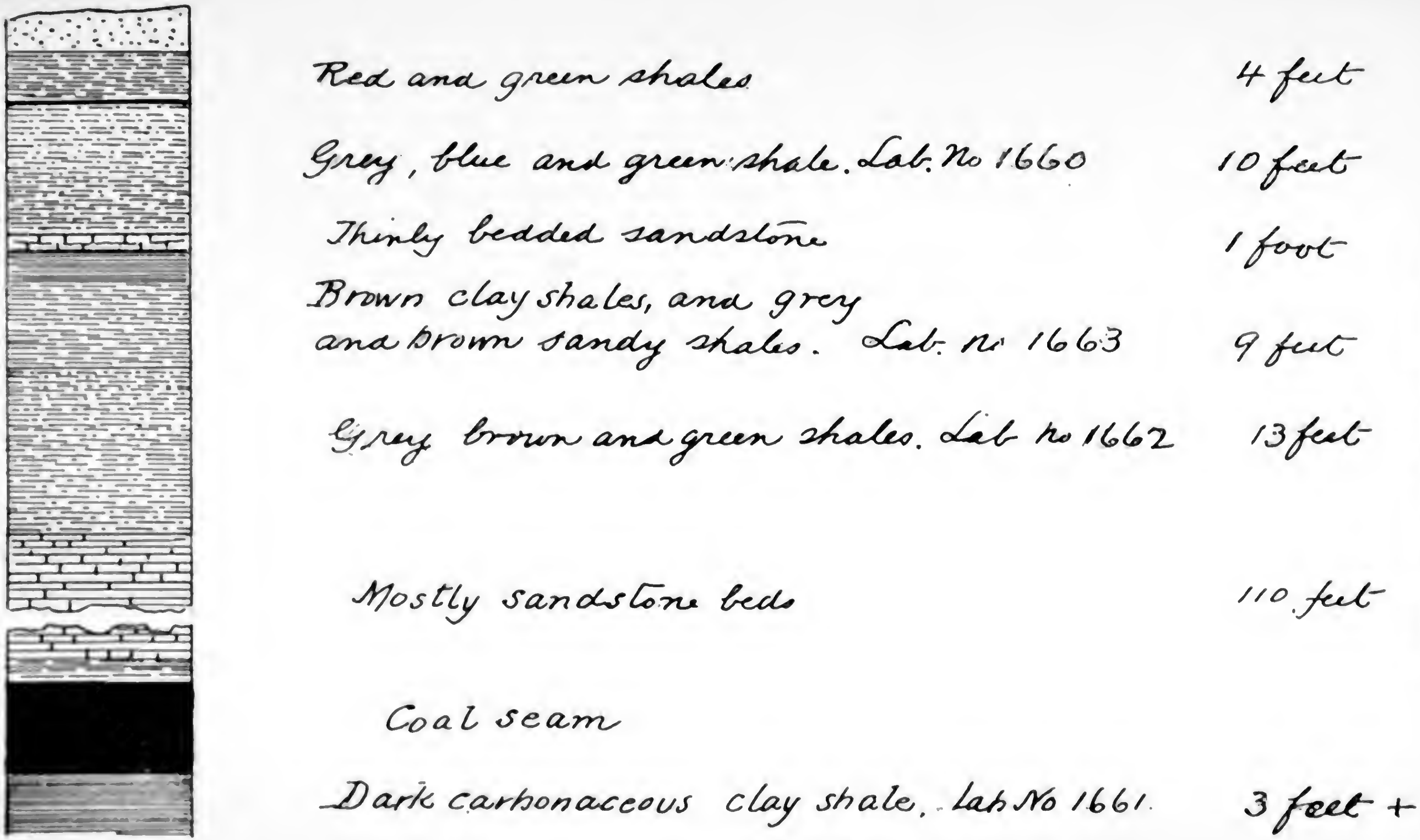

FIG. 2—Section of shale beds at Entwistle, Alta.

Pre-heated to 500°C, plasticity still good, clay granular, but dried without cracking, even moderately fast.

The tests of these three are given below:

	1661	1661A	1661B
Water required	35	26	....
Air shrinkage	10·2	7·6	4·7
Cone 010			
Fire shrinkage	.6	1·5	·7
Absorption	14·54	14·28	20·19
Colour	Light red	Light red	
Cone 03			
Fire shrinkage	7·3	6·7	
Absorption	1·04	4·2	
Colour	Red brown	Red	
Cone 1			
Fire shrinkage		7·3	7·
Absorption		1·0	2·8
Colour		Red brown	
Cone 3			
Fire shrinkage		....	8·6
Absorption		....	3·76
Cone 5			
Fire shrinkage	5·0	....	
Absorption	1·0	....	
Colour	Brown	....	
Cone 13	Vitrified		

Kananaskis to Cochrane, Alta.—The Rocky Mountains end in a pronounced escarpment at Kananaskis. From there eastward the country consists of low foothills which merge into the plains. Underlying this region are beds of shales and sandstones chiefly Cretaceous, the whole series being highly folded. At Seebe Siding east of Kananaskis the flat lying Cretaceous shales have been opened up in a pit along the Bow River, in order to obtain material for the cement works at Exshaw. They are very siliceous, hard, and not adapted to the manufacture of clay products. Eastward from here sandstone and shales appear to be rather scarce, except between Radford and Mitford, where they are worth investigating.

Tertiary formation.—This overlies the Edmonton series and forms a broad belt extending from somewhat north of the Grand Trunk Pacific Railway, west of Edmonton, southward almost to the international boundary.

The formation consist of shales and sandstones, often alternating in rapid succession, but the minute stratigraphic details have not been worked out in any of the areas. Outcrops are also scarce as the formation is heavily and extensively covered by Pleistocene materials. It includes the shale areas examined at Red Deer, Calgary, Sandstone, and on Pincher Creek by Pincher.

Calgary region.—The region about Calgary is underlain by Tertiary shales, but unfortunately there are few outcrops owing to the extensive and usually thick deposit of Pleistocene gravels and silts. They are to be looked for especially in the valleys, but if present, the wash from the upper slopes though thin may be sufficient to conceal them.

At present these shales are worked at two localities, viz., Sandstone, south of Calgary, and Brickburn, west of Calgary. At both these localities considerable trouble is caused by the numerous sandstone layers in the shale, which have to be discarded in mining.

It would be well worth careful prospecting to find some localities at which the sandstone layers are obscure. Such a one was found by us east of Cochrane. The several localities in the Calgary region may be referred to separately.

Brickburn.—This locality is about five miles west of Calgary on the south side of the Bow River Valley. The valley here is quite broad, and the Bow meanders through it, but here and there has cut a cliff in the sides, exposing beds of shale.

The Calgary Pressed Brick and Sandstone Company has opened up a bank in a bluff about 100 feet above the river level, at a point where the shale outcrop is hidden under a thin sheet of wash and talus. The excavation, about thirty feet in height, exposes a series of beds of hard sandy brown shale, soft brown shale, thin layers of blue shale and beds of sandstone. The sandstone and shale beds alternate and there are no beds of the latter which are over three feet in thickness. In blasting down the material the shale becomes more or less thoroughly shattered, but the sandstone is left in large blocks. This facilitates its removal, which is fortunate, since it constitutes about thirty per cent. of the material in the bank. But little prospecting appears to have been done to ascertain whether a better deposit of material could be found in the immediate vicinity. This cannot be accomplished without test pitting and trenching as most of the surface, including the steep slope leading down to the river, is covered by a silty clay containing lime pebbles. That other material may be present is indicated by the fact that along the railroad track there is a mass of shale which has slid down from a higher level.

At present the bricks are made from the shale obtained from the quarry near the top of the bluff, and the tests of this material (1703) will be found in the table at the end of this paper. This shale burns to an excellent red colour, and makes a dry-press brick.

Sandstone, Alberta.—Along the branch of the Canadian Pacific Railway from Calgary to McLeod there are few outcrops until Sandstone is reached. Here the railway passes through a somewhat narrow valley, whose sides are rather steep, and afford some exposures of the Tertiary shales and sandstones. The best section, however, is that shown in the quarry of the Canadian Cement Company, where a face about fifty feet high has been opened up, exposing a series of alternating layers of sandstone with blue and grey shales. The shaly layers are from eight inches to two feet, and vary in thickness from point to point in the quarry, the same being true of the sandstone. There may thus be an excess of sandstone in one part of the quarry, or of shale in another.

The shale is hard, fine-grained, with a splintery break and conchoidal fracture. The blue if used alone is said to crack in water smoking, but the grey does not, nor does a mixture of the two. The blue seems to disintegrate less readily, and the grains of it in the brick are often coarser than the blue.

In testing the quality of the material from this bank a full test was made of the ground mixture, as prepared for dry-press, and a partial test of each of the shales alone. Tests are given in the table (Nos. 1704, 1705, 1706).

Cochrane, Alberta.—This locality is on the Canadian Pacific Railway about thirty miles west of Calgary. The town itself lies on a terrace that is underlain by calcareous clay, and extends to the foot of the ridge forming the north wall of the Bow River Valley. Outcrops in the ridge at Cochrane are few, and seem to be chiefly sandstone. Interbedded shales may be present, but if so the wash covers them.

One mile east of the town a railway cut in the steep slope bordering the river, exposes a fine section of bluish shales and interbedded sandstone. The former in their general appearance much resemble those found east of Bermis. As this section is in a bluff overhanging the railroad, there is no possibility of working it without causing slides to occur on the track, and so only a small sample was taken with the object of securing information concerning the character of the material in this vicinity.

A test of this shale (1708) showed it to be somewhat calcareous although with 20 per cent of water it worked up to a mass of good plasticity, showing however some grit. The average air shrinkage was 5 per cent, and the colour, after burning, a good red. It was nearly steel hard at Cone 010.

The fire shrinkage and absorption were respectively ·3 per cent, and 17·68 per cent at Cone 010, and ·6 per cent and 17·38 per cent at Cone 03. The shale fused at Cone 1.

Eastward from this cut are a number of small spurs, extending out from the main ridge, and in the coulees between these spurs shale outcrops are sometimes found. In the first of these east of the cut from which sample 1708 was taken, is a deposit of shale at least forty feet thick, which is free from sandstone, but grades upward into shaly sand.

The deposit of shale must be of some extent, as evidence of it is seen in coulees to the eastward, where it is covered by a thin wash of gravel. This section stands in rather strong contrast to those noted from Brickburn and Sandstone, and shows the possibility of finding shales free from interbedded sandstones in this region.

Didsbury, Alta.—This town is situated near Rosebud Creek, about fifty miles north of Calgary. A brick yard was started here three years ago, on the property of Wm. Hunsperger, but it was only in operation for a short time; the plant being afterwards moved to Camrose.

Wire-cut bricks were made from the decomposed portion of a bed of shale which outcrops in the bottom of a small coulee near the Canadian Pacific Railway line. The plant was badly located, as the shale is not very accessible at this point, being overlain by twenty feet or so of sandstone and glacial drift, and the amount of weathered material exposed in the bottom of the coulee is small.

The shale in the neighbourhood of Didsbury occurs in a horizontal bed and includes a thin seam of lignite. It is thick enough to be worked for brickmaking purposes, but for economical operation must be found at a spot where the sandstone capping is worn off, so as to allow of the working of the material in open pits. Such favourable conditions could no doubt be obtained by prospecting.

The shale (1702) is of yellowish colour, calcareous, very plastic and smooth, easy to work, and gives no trouble in air drying. The air shrinkage is 5·6 per cent.

Red Deer, Alta.—The only clays in use at this locality are of Pleistocene age, occurring in the heavy lake deposits of this formation. Miocene shales are known, however, to underlie this region and are exposed on the right bank of the Red Deer River, above the railroad bridge.

Above the bridge for a short distance is a fifteen foot terrace underlain in its upper portion by gravel, but below this and outcropping in the face of the bank are grey shales, which rarely extend more than ten feet above the river level. These are not very persistent, for up-stream the shale passes into sandstone. About three-quarters of a mile up-stream, the high bluffs on the same bank of the stream show about twenty five feet of shale, overlain by about fifty feet of till with lenses of silty clay in it.

Below the waggon-bridge close to town, the shale outcrops, but is very sandy. Heavy bodies of shale over the coal seam are reported to occur, about eight miles down the river.

At the fifteen foot terrace previously referred to, the following section was noted:

Soil.	1 ft.
Gravel	2 ft.

Shaly sandstone	2 ft. 6 in.
Shale	3 ft.
Rock	6in.
Lignite, thin layer	2 in.
Shale (1655)	10 ft.

The tests of this ten foot bed of shale, whose exact location is s.e. corner, sec. 17, twp. 38, 27 w., are given in table at the end of the paper.

MOUNTAIN REGION.

Under this designation is included the region bordered on the east by the Great Plains, and on the west by the Coast Range, and so far as known does not contain extensive clay resources. Moreover, even those which do occur in this region cannot be of great commercial value unless situated close to lines of transportation.

Shales are rare because in most instances deposits of argillaceous material have been altered to slaty rocks or schists.

Extensive deposits of surface clays are also rare, and those which are present are mostly of small size and of silty character.

SHALES.

Blairmore, Alta.—The Kootanie shales outcrop at the base of the hill on the south-west side of the valley. The material is a siliceous, ferruginous, fissile shale, containing occasional sandstone streaks and scattered concretions of iron carbonate. It appears hard when fresh, but nevertheless grinds up rather easily. We have no tests of it, as the samples collected were lost in transit, and we can only state that it is red-burning and non-refractory. The material is utilized in the manufacture of dry-press brick.

Coleman, Alta.—The same shale is exposed in the hillside near the entrance to the main slope of the International Coal and Coke Company, and probably would give similar results to that used at Blairmore. Our sample of this was also lost.

Elko, B.C.—A talcose shale which occurs in the vicinity of Elko, has been regarded by some as a fire-clay, and several samples of this material were shown us during the summer. We did not visit the deposit, but a sample of the clay was tested and found not to be of refractory character, as it fused completely below Cone 27.

Collins Gulch, B.C.—Nothing definite is known regarding the occurrence of this shale, except that it was obtained from the tunnel of the coal mine by Mr. Chas. Camsell of the Canadian Geological Survey, and sent to us for testing.

The material (1742) is quite plastic, but checks rapidly in air drying. Pre-heating to 550° C. did not destroy the plasticity, but permitted slow drying, without cracking. The air shrinkage is 5·3 per cent, and the fire shrinkage at Cone 5 is 8 per cent. At this cone the absorption is 6·8 per cent. The clay is not fused even at Cone 13, but is not a fire clay. This would seem to be an excellent pressed-brick clay, if the cracking could be overcome.

SURFACE CLAYS.

Field, B.C.—At the base of Mount Stephen, and close to the railway yards of the Canadian Pacific railway, is a heavy deposit of tough stony clay, which belongs to the colluvial type of deposit.

The clay (1713) is derived from an easily decomposed schist on the slopes of Mount Stephen, and has slid to the bottom of the slope. The stones are as a rule partly decomposed schist fragments. It burned to a brick red body.

Yoho Valley, B.C.—Along the new waggon road up the valley, about one mile before reaching the "Lower Camp", the road cuts through a deposit of yellowish-brown laminated and highly calcareous clay. The clay (1712) is not strongly plastic, and has, moreover, a toughness and springiness which interfers somewhat with easy moulding. It can, however, be cast into cheap pottery. After burning it has a cream colour.

There are other scattered deposits of sandy surface clays in the mountain region, but they are of little importance. Deposits are worked for common brick at Nelson, Castlegar Junction, Enderby and Kamloops.

PACIFIC COAST REGION.

This includes the territory lying west of the Coast Range, and while limited in the extent of its clay resources, contains a considerable variety so far as our investigations have gone.

The most important shale deposits are those of Sumas Mountain, east of Vancouver, which, as shown by the tests given on other pages, represent one of the most important series found in Canada. No other shale deposits of economic value and favourably located are thus far known to occur on the mainland elsewhere in this region.

On Vancouver Island shales are found associated with the Tertiary coals at Nanaimo and Comox, but most of those thus far discovered appear to be too sandy or too carbonaceous for use. Some has been obtained from Nanaimo and more recently from Comox, for use in the sewer-pipe mixture at the pipe works near Victoria. It serves well for this purpose, but is of little value if used alone.

Much is heard locally regarding the value of the shale deposits said to exist on Mayne and Pender Islands. It is true that there are shaly deposits on these Islands, but the shale deposits so far as our experience goes, consist of thin layers, interstratified by thin beds of sandstone, and Mr. C. H. Clapp, who has carefully examined both of these Islands, corroborates our view.

The surface clays are more extensive than the shale deposits in the Pacific Coast region.

In the vicinity of Vancouver are a number of deposits of grey, stratified surface clay suitable for common brick. Similar clays occur in the immediate vicinity of Victoria, and also on several of the islands between Vancouver Island and the mainland. They probably represent re-worked glacial clays.

One of the most interesting deposits, however, is the residual clay from Kyoquot on Vancouver Island, which is of refractory character.

Tertiary Shales.

Clayburn, B.C.—The most important series of clay deposits found in the Pacific Coast belt are those lying in Sumas Mountain, east of Clayburn on the Seattle branch of the Canadian Pacific railway.

The works of the Clayburn Brick Company are situated one mile east of Clayburn station, at the base of the mountain.

Sumas Mountain is a heavily wooded hill rising above the surrounding prairie to an elevation of several hundred feet. It consists of a series of shales, sandstones and a few conglomerates and coal beds, the whole series having a gentle south-west dip.

Owing to the somewhat heavily wooded character of the surface, outcrops are scarce, except in the steeper ravines, while the lower slopes are mantled by a covering of clay and sands of Pleistocene age, and landslides.

The shales were visited at two places. The first of these was along the line of the Clayburn Brick Company's narrow gauge railway running three and a half miles east from the factory. The other was at Kilgard on the south side of Sumas Mountain.

Clayburn Brick Company's deposits.—About one thousand feet from the brick works along the narrow gauge railway, is a bank of blue grey surface clay, which is dug with a steam shovel. This is used for common brick, and is of the same character as that found and worked at New Westminster. This type of material is found in the ravines for some distance up the track, as well as up to an elevation of about 150 feet above the valley.

The first shale exposures are reached about two miles up the railway track. At this point the shale outcrops on both sides of the track, and is overlain by a coarse conglomerate, composed of fragments of shale, granite, feldspar, etc. The outcrop is not of great length, but from the scant evidence available we are inclined to believe that the shale deposit may be of lenticular character.

The shale is separable into two beds, viz., a lower grey shale of smooth, plastic character, and an upper, purplish one, which is harder and grittier. The former is buff-burning, and on the south side of the track is at least six feet thick, while the upper or grey burning shale is four to six feet thick.

The workings have not been driven more than 100 feet, and for part of this distance both beds are worked out, leaving a chamber about ten feet high. If this practice is continued, care should be taken to properly timber the workings.

A test made of the buff-burning or lower shale (1724), which is the one most used, showed it to be of good plasticity, and with the exception of 1728, the most plastic of the Clayburn series tested. It burns to a good buff pressed brick.

At the end of the narrow-gauge road, three and a half miles from the works, the company obtains its fire clays from a small mine. The section, as near as can be made out, shows:

Sandstone	
Upper fire clay	8 ft.
Coal, with flint clay partings . .	6 in. to 1 ft.
Lower fire clay.	7 ft.
Ferruginous clay.	4 ft.
China clay	10 to 15 ft.

In mining the material, no attempt has been made in the past to keep the two fire clay beds separate, but this should be done, unless it is known that they are alike. The need of care in mining is well shown by our own tests. (1722).

The first of these was made on an average sample of seventy five pounds collected from the stockpile at the brick works, and said to represent the run of the mine.

The china clay (1721) is a fine-grained whitish shale, sometimes soft and smooth, at other times hard and porcelain-like, with a conchoidal fracture. It grades upwards into an iron-stained whitish shale. There are numerous small limonite spots scattered through it.

Kilgard.—A series of shales similar to those seen east of Clayburn, are exposed on the south-east side of Sumas Mountain, on the property of Messrs. Maclure. On this side of the mountain the land rises steeply from the prairie to the summit of the mountain, being interrupted by two benches (Fig. 3).

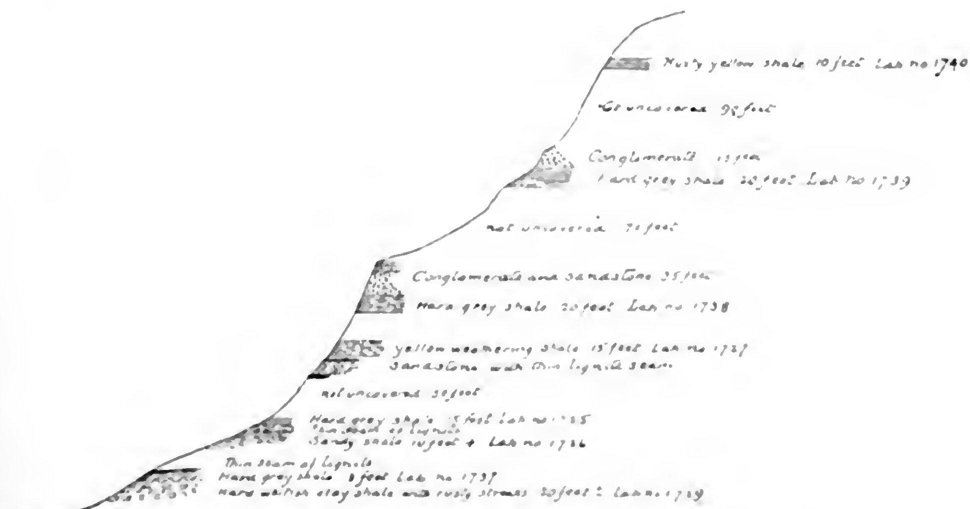

FIG. 3—Section of shale beds in Sumas Mountain, B.C.

The best series of exposure is in the s. w. ¼, sec. 29, twp. 19, in a steep ravine, which is crossed by a waggon-road bridge. A section up the south face of the mountain, along the line of this stream, is given in Fig. 3, and is compiled from data supplied by Mr. J. C. Maclure who made the survey.

This section shows a series of shales and sandstones similar to that found to the north, on the property of the Clayburn Company, Ltd., and from what can be told from the limited exposures along the creek, the dip may be south-west. The shales in this section present considerable variety and include fire clays, sewer pipe and paving brick clays, and red and buff burning shales adapted to the manufacture of pressed brick.

The tests of these are given in the table (See Nos., 1725, 1726, 1727, 1729, 1737, 1738, 1739, 1740).

SURFACE CLAYS.

Vancouver and vicinity.—Surface clays only are available in the region about Vancouver. Shales underlie the surface formations, and are sometimes exposed in excavations for foundations or sewers, but they usually lie under too deep a cover to be worth working.

The common type of clay used for brick making here is a bluish-grey, laminated clay, containing very thin sand layers. The clay appears to lie in beds, but these if traced for any distance often thin out, while the sand which over and underlies them appears to increase in thickness. The formation then consists of a series of clay lenses surrounded by ferruginous sands. There appears to be rather strong evidence that the formation is of interglacial character, for glacial drift is found both above and below it.

A good example of the mode of occurrence of this clay deposit can be seen near the yard of the Fraser River Brick Company, on the south side of the Fraser River, about two miles south-west of New Westminster.

About 500 feet west of the yard, the clay is fifteen feet thick but thins out completely to the eastward, its place being taken by sand. Nearer to the yard another clay lens begins, thickens to about two and a half feet and then thins out again. East of the yard is still a third lens with a maximum thickness of perhaps fifteen feet.

Again at the yard of Coughlan and Sons, just east of New Westminster, the clay shows the same lens-shaped character, and in the bank being worked in September 1910, the section showed:

Boulder clay	0—6 ft.
Laminated blue clay	20 ft.
Gravel	

This blue-grey clay appears to show such uniformity in its character and workings properties that a test of an average sample obtained from the yard of Coughlan at New Westminster will serve to show its quality. (See table No. 1720).

Anvil Island.—This is an island of metamorphic rock, situated in Howe Sound, about twenty-three miles from Vancouver. The slopes descend rather steeply towards the water, with some bench-like interruptions, but here and there are depressions in which pockets of drift and clay have been deposited.

The deposits of the latter are being worked on the south side of the island, one of them by the Columbia Clay Company, and the other by the Anvil Island Brick Company, Ltd.

At the former the deposit consists of a stratified clay with scattered boulders and is thought by C. H. Clapp to be a re-worked glacial deposit. The clay, which is hard, tough and silty, is yellow above and bluish-grey below. Both varieties appear hard and dry in the bank, but when worked for a few minutes between the fingers, become soft and moist and little water has to be added to them.

A sample of the buff or upper clay (1733) was given a few tests, and the results appear in the table.

Vancouver Island.—The clay and shale resources are of limited occurrence. Pleistocene clays are found at a number of points and are often interbedded with or overlain by sand and gravel. They may represent deposits of glacial till, lake clays, estuarine formations, or lenses in delta deposits.

Few of them are worked except those near Victoria, and all so far as known appear to be red burning. Their chief use is for common brick, and for this purpose the more sandy phases are used. The smoother beds are useful for drain tile and flower pots, but many of these have a high air shrinkage.

Tertiary shales are associated with the coals at Comox and Nanaimo, but they are usually too gritty to be used alone, but can be mixed with other clays to good advantage.

A remarkable clay has recently been found near Kyoquot on the north-western side of Vancouver Island. It appears to be a residual clay derived from metamorphosed rhyolite, and is one of the most refractory clays found in western Canada. Its tests are given in the table under No. 1735. This clay is mixed with the Comox shale for making sewer pipe.

CONCLUSIONS.

The foregoing brief review will serve to show that the western provinces contain a variety of clays, many of them of excellent quality, including good grades of fire clay.

Up to the present time most of these have been little developed owing to a limited demand for burned clay wares. For the most part this demand has been supplied by foreign manufacturers, who, aided by a low tariff, have shipped in their wares at a good profit. The probabilities are, however, that with the rapid settlement of the west and the growth of many towns and cities requiring clay products, the western clay resources will be developed in response to a constantly increasing demand.

SUMMARY OF CLAY TESTS

		Lab.	% H_2O	Air Shr.	Tem. Shr.	Cone 010		Cone 03		Cone 1		Cone 3		Cone 5		Cone 9		Fus.p't	Colour	Remarks
						Fire Shr.	Abs.	Fire Shr.	Abs.	Fire Shr.	Abs.	Fire Shr.	Abs.	Fire Shr.	Abs.	Shr.	Abs.	Cone		
Surface clay, Portage la Prairie	Man.	1621	24·8	6·2	269	s. s.	20·56	0·0	20·15	.300x	9·00x							1	Buff	
" Neepawa	"	1622	23·	6·8		0	21·36	0·0	20·19	Fused								1	Light red	Plas. fair, much fine grit.
Pierre shale, Riding mountain	"	1623	37·8	4·9	113	2·4	28·73	4·0	24·45	5·00	19·54	6·4	16·07						Brown	" low.
Surface clay, Birmis	"	1624	35·	6·6		2·	28·36	3·6	22·54	8·60	6·30								Buff	
Pierre shale, Riding mountain	"	1625	40·4	5·6		1·6	23·16	3·7	17·26	5·7	10·4			10·4	4·42				Red	" fair, hard to work.
Surface clay, Gilbert Plains	"	1626	27·2	8·2	252	1·6	23·97	·3	23·51	6·7	5·36							4	Buff	
" Hartney	"	1631	22·	5·2		s s	19·94	2·0	16·38	2·30	7·66							5	Buff	Good. Fine grit.
Pierre shales, Souris	"	1632	42·2	6·	120	·9	32·81	3·0	27·45	7·30	15·32			7·7	12·30	Vitrified		12^{2}	Red-brown	
Surface clay, Virden	"	1633	29	6·5	210	·4	26·47	0·0	26·56	11·60	Vitrif.							3	Buff	
Pierre shale and surface clay, Virden	"	1633A	36	4·2		2·3	27·45	·7	27·45	7·00	7·17	8·6	4·82					5	Red	
Pierre shale, Assiniboine river	"	1634	37·8	2·8		1·5	35·59	1·3	33·33	3·4	33·00			5·7	23·37				Red	
Pierre shale and surface clay, Ninette	"	1635A	37·	5·8		2·	23·18	3·0	16·73	5·4	13·75								Red	
Niobrara shale, Leary	"	1636	32	9·2	349	·6	15·21	9·6	·21	3·0	·65							5	Red	
Sufrace clay, Winnipeg	"	1637	28·2	4·5	240	−2·5	31·44	−2·4	31·42	2·4–	28·37	−1·7	27·13					5	Buff	
Underclay "	"	1638	39	10·3	248	3·7	13·31	3·4										1	Red	
" Morris	"	1640	37·5	11·1		3·	10·42	4·7	2·74									1	Red	
Shale over coal, Pinto	Sask.	1641	30·8	7·5	293	1·	22·28	1·0	21·70	8·7	0·0							3	Pink buff	
" at surface "	"	1642	34·	9·2		1·5	14·36	8·6	Vitrified									5	Red	
" under caol, "	"	1643	30·	8·		1·7	13·60	7·4	"										Red	1% trace.
" " " Estevan	"	1644	33·4	9·6	325x	0·5	14·00	6·3	"									3	Red	
Surface clay, "	"	1645	21	5·	334	s. s.	24·48	s. s.	23·94	0·4	19·76							3	Buff	
Brown shale, Dirt Hills	"	1646			High	1·7	14·7	9·3	8·31	13·3	0·0							2	Brown	Pre-heated to 500° C.
Dark grey clay "	"	1647	30·	8·5	334	·2	16·38	4·4	7·52	5·4	3·92	5·30	4·39						Red	
Light grey sandy clay, "	"	1648	27	6·1	123	0	18·58	2·7	15·41	3·3	13·19			2·7	10·70	3·3	9·81	32	Grey white	
White clay, "	"	1649	30	7·7		·4	16·74	3·7	10·34	5·3	7·69			6·6	4·67	6·6	2·60	31	White	
Grey fire clay, "	"	1650		7·8		1·0	16·76	3·6	11·60	6·0	8·23			6·6	4·37	8·4	2·25	32	"	
Surface clay, Prince Albert	Sask.	1652	29	9·	380	·0	15·16	1·0	14·26									2	Red	
" Edmonton	"	1653	20	5·6	212	s. s.	21·75	s. s.	17·84	4·0	1·75							2	Red	
" "	"	1654	25·5	8·	275x	s. s.	18·16	5·3	5·94	Vitrified			Vitrif.					1x	Red	
" "	"	1655	25	8·2	335	·2	16 63	2·0	11·02	4·6	0·0	4·7	0·00					5	Red	
" with sand, Edmonton	"	1655A	23·5	6·5		0	14·68	2·3	8·85	3·3	1·52							5	Red	
Shale, Edmonton	"	1656	28·6	10·4	270	·2	14·24	3·7	9·23	4·3	·8	6·7	1·50					5x	Red	
" "	"	1657	33	8·1		2·2	17·30	2·4	14·09										Red	
" "	"	1658	35	13·1	150^{2}	2·1	12·08					6·0	1·20					5	Red	
Surface clay, Edmonton	"	1659	34	8·9		1·4	13·84	4·3	4·60				Vitrif.					5	Red	
Shale, Entwistle	"	1660	24·2	6·7		0	14·58	4·4	6·05			6·7	10·00						Red	
Underclay, "	"	1661	35·	10·2		·5	14·54	7·3	1·04					5·00	1·00			15	Brown	
" "	"	1661A	26·3	7·6		·5	14·28	6·7	4·62	7·3	1·4								Dark red	
" "	"	1161B		4·7		·7	20·19			7·3	1·06	8·6	3·76						Brown	
Shale, "	"	1662	22	4·8	381	s. s.	14·62	3·0	6·02	5·0	0·0	6·0	0·0					5x	Red	
" "	"	1663	22·5	4·7	198	s. s.	17·96	3·6	8·72	9·0	0·75							3	Red	
Surface clay, Red Deer	"	1664	25	7·6	268	1·6	18·21	3·4	13·22									1	Red	
" "	"	1664A	22	4·8	273	s. s.	24·36	s. s.	23·72									2	Red	
Shale "	"	1665	25	6·9	176	·8	19·34	1·0	18·47									1	Red	
" Letbbridge	"	1666	25	6·3		·7	15·42	8·0	3·22			6·3	1·93					5	Dark red	
Surface clay, "	"	1667	19	4·				0·0	13·58										Red	
Shale, Milk Creek	"	1668		6·4		·4	11·47	4·3	Vitrified		·4							7	Red	
" "	"	1669	25	6·5	150^{2}	s. s.	14·14	1·6	7·64	2·00	6·11							7	Red	
" "	"	1670	21	6·3		s. s.	12·17	2·0	7·64	2·70	3·30								Red	
" "	"	1671	21	4·5		s. s.	12·38	2·0	5·41	3·00	2·58								Red	
" Pincher	"	1672	24·2	7·7		·8	14·63	6·0	4·65	Past Vitrific								3	Red	
Surface clay, 7 miles W. of Pincher	"	1673	29	8·8	300x	1·3	11·68	3·7	1·54									1	Red	
Surface clay, 7 miles W. of Pincher	Sask.	1674	25	6·5		·6	18·02	0·0	16·90										Red	
Shale over coal, Oldman river	"	1675	28·6	8·9	205	s. s.	15·36	0·0	13·83	3·7	5·95	3·8	4·8		Vitrified			9	Grey	
Shale, 1 mile W. of Lundbrek	"	1679		4·6		·4	14·17	3·3	7·75	s. s.	1·6								Red	
Shale, bet. Bermis and "	"	1680		4·7		s. s.	12·75	2·7	5·84									1	Red	
" " "	"	1682		5·4		·5	13·96	0·7	12·80									1	Red	
" " "	"	1683		5·5		1·0	10·40	5·7	1·40	2·30	0·00							7	Red	
" " "	"	1684		4·0		s. s.	13·71	s. s.	11·37	2·30	4·28	0·40	7·58					6	Red	
Clay under lignite, Red Cliff	"	1685	28·2	4·4	297	s. s.	22·36	0·0	22·27	1·3	14·00							3	Red	
Yellow clay shale, "	"	1686	30	11·	305	s. s.	10·77	2·3	4·18	5·00	1·34	4·6	0·5					5	Dark red	
Shale over lignite "	"	1687	43·8	11·6	High	·7	10·82	2·0	6·07	0·0	3·4							5	Red	
Green wire cut brick, "	"	1688	19·4	7·2	378	0	11·59	0·4	8·87	3·00	3·44		Vitrif.					5	Red	

Shale,		1662																		
"	"	1663	22·5	4·7	198	s. s.	17·96	3·6	8·72	9·0	0·75							3	Red	
Surface clay, Red Deer	"	1664	25	7·6	268	1·6	18·21	3·4	13·22									1	Red	
"	"	1664A	22	4·8	273	s. s.	24·36	s. s.	23·72									2	Red	
Shale "	"	1665	25	6·9	176	·8	19·34	1·0	18·47									1	Red	
" Lethbridge	"	1666	25	6·3		·7	15·42	8·0	3·22			6·3	1·93					5	Dark red	
Surface clay, "	"	1667	19	4·				0·0	13·58										Red	
Shale, Milk Creek	"	1668		6·4		·4	11·47	4·3	Vitrified		·4							7	Red	
" "	"	1669	25	6·5	150[2]	s. s.	14·14	1·6	7·64	2·00	6·11							7	Red	
" "	"	1670	21	6·3		s. s.	12·17	2·0	7·64	2·70	3·30								Red	
" "	"	1671	21	4·5		s. s.	12·38	2·0	5·41	3·00	2·58								Red	
" Pincher	"	1672	24·2	7·7		·8	14·63	6·0	4·65	Past Vitrific								3	Red	
Surface clay, 7 miles W. of Pincher	"	1673	29	8·8	300x	1·3	11·68	3·7	1·54									1	Red	
Surface clay, 7 miles W. of Pincher	Sask.	1674	25	6·5		·6	18·02	0·0	16·90										Red	
Shale over coal, Oldman river	"	1675	28·6	8·9	205	s. s.	15·36	0·0	13·83	3·7	5·95	3·8	4·8		Vitrified			9	Grey	
Shale, 1 mile W. of Lundbrek	"	1679		4·6		·4	14·17	3·3	7·75	s. s.	1·6								Red	
Shale, bet. Bermis and "	"	1680		4·7		s. s.	12·75	2·7	5·84									1	Red	
" " "	"	1682		5·4		·5	13·96	0·7	12·80									1	Red	
" " "	"	1683		5·5		1·0	10·40	5·7	1·40	2·30	0·00							7	Red	
" " "	"	1684		4·0		s. s.	13·71	s. s.	11·37	2·30	4·28	0·40	7·58					6	Red	
Clay under lignite, Red Cliff	"	1685	28·2	4·4	297	s. s.	22·36	0·0	22·27	1·3	14·00							3	Red	
Yellow clay shale, "	"	1686	30	11·	305	s. s.	10·77	2·3	4·18	5·00	1·34	4·6	0·5					5	Dark red	
Shale over lignite "	"	1687	43·8	11·6	High	·7	10·82	2·0	6·07	0·0	3·4							5	Red	
Green wire cut brick, "	"	1688	19·4	7·2	378	0	11·59	0·4	8·87	3·00	3·44		Vitrif.					5	Red	
Stiff clay in lenses, Medicine Hat	Alta.	1690	33·8	11·9	300	1·	10·55	0·7	9·31									1	Red	
Grey sandy clay, Coleridge	"	1691	24·5	8·	387	s. s.	10·67	0·6	7·27	4·30	3·78	4·60	2·00					5	Red	
Black carbonaceous clay,"	"	1692	21	8·5	334	s. s.	10·50	s. s.	6·56	2·40	3·89			3·0	2·34	Vitrified		15	Grey	
Buff shale, "	"	1693	22	7·		·2	12·94	4·6	2·60									1	Red	
Brown sandy shale, "	"	1694	21·2	7·2	270	0	12·00	3·4	4·76	4·4	3·26								Red	
Shale over coal seam, Medicine Hat	"	1695		6·7		·4	20·62	7·3	6·92	7·4	0·73								Red	
Shale, Anslee coal mine	"	1696	31	10·8		·6	12·04	5·3	2·10										Red	
Grey clay, Irvine	"	1697	36	9·4		·2	16·40	2·3	6·85										Red	
Red shale, "	"	1698	36·6	9·7		2·	18·30	6·0	10·16										Red	
Hard grey shale, "	"	1699	33·3	11·6		·4	15·57	2·0	10·48										Red	
Surface clay, Medicine Hat	"	1700	18·4	5·2		s. s.	12·52	0·7	9·81										Red	
" N. of "	"	1701		10·7		·4	13·05	3·4	6·81										Red	
Shale, Didsbury	"	1702		5·6		·7	24·03	0·4	24·80	5·70	13·18								Buff	
" Brickburn	"	1703	17·6	5·	154	·6	13·43	2·3	8·73									1	Red	
Green shale brick, Sandstone	"	1704	19·	6·	165	·4	14·90	2·3	9·46									1	Red	
Grey shale, "	"	1705	21	5·		·2	15·56	2·3	13·67									1	Red	
Blue shale, "	"	1706	21	6·8		1·4	12·82	5·45	5·58									1	Red	
Buff shale east of Cochrane	"	1707	21·2	5·5	128	·7	18·73	2·0	15·57									1	Red	
Blue " " "	"	1708	20	5·		·3	17·68	0·6	17·38									1	Red	
Surface clay, "	"	1710	26	7·9		·5	21·98	0·3	20·96									1	Buff	
" Canmore	"	1711	22	4·2		s. s.	35·41	s. s.											Buff	
" Yoho Valley,	B.C.	1712	28.2	5·	111	s. s.	37·92	s. s.	40·00									1	Buff	
Colluvial clay, Field	"	1713	20	2·7		s. s.	21·95	s. s.	20·00	s. s.	16·65							5	Red	
Surface clay, Nelson	B.C.	1714	28	5·0		0	23·94	2·0	18·33									2	Red	
" Enderby	"	1715	28·2	6·3	290	0	20·76	3·0	14·77	7·3	·20							5	Red	
Weathered surface clay, Kamloops	"	1717	23	4·6	156	s. s.	19·12	2·0	11·74									1	Red	
Hard " " "	"	1718	27	8·4		2·2	18·36	3·3	0·15									1	Red	
Surface clay, New Westminster	"	1720	19	4·3	256	·4	15·35	1·7	10·44									1	Red	
Hard white clay shale, Clayburn	"	1721	16	3·2		s. s.	14·57	s. s.	13·53	0·30	12·76			0·6	11·21	1·2	9·72	22	Whitish	
Fire clay, "	"	1722	16	3·	78	1·5	15·89	2·3	13·63	3·10	12·30			3·6	10·96	4·0	9·75	17		Selected sample fused Cone 32.
Yellow shale, "	"	1723	19	5·	196	·3	16·16	4·0	8·28	6·00	3·34	7·00	2·90						Red	
Purple shale, "	"	1724	17·6	6·1	108	·8	14·32	2·7	9·20	5·00	7·00			6·0	1·43	7·0	·20			Vitrified at Cone 12.
Fire clay, Kilgard	"	1725	15	3·	103	·6	14·42	1·0	14·21					3·3	10·95	3·6	8·67	27x	Pink-buff	
Hard grey sandy shale, "	"	1726	16·8	3·		·0	18·58	0·6	17·20	2·3	12·50			5·3	9·50	4·6	2·26		Light brown	
Yellow shale, "	"	1727	20·2	4·	114	·6	17·73	2·0	15·21	3·3	13·54			4·7	10·42	5·0	10·29		Buff	
Rusty " "	"	1728	22	4·8		2·2	15·54	4·0	11·93	7·0	7·57			Not vitrified					Red	
Hard grey and white clay shale, "	"	1729		2·		s. s.	14·00	1·0	12·95					1·0	11·00	1·00	9·34	22x	Grey-white	
Grey burning shale, Clayburn	"	1730	15·4	3·6		0	15·82	0·4	14·28	1·7	11·00			3·7	3·06				Drab	
Lower fire clay. "	"	1731																31		
Dark grey shale, Comox	"	1733	26·4	6·	283	·3	16·74	3·0	7·76									1	Red	
Residual clay, Kuyoquot	"	1734	15·6	2·6		·6	16·00	1·4	13·47	2·3	13·72			5·0	6·31				Drab	
Surface clay, Victoria	"	1735	20	3·	84	s. s.	15·50	s. s.	14·22	s. s.	11·70			0·6	9·23	1·7	7·92	30	Pink grey	
Hard grey shale (fire clay), Kilgard	"	1736	28·2	7·9	364	·5	15·61	8·0										1	Red	
Shale, "	"	1737	14	2·4		0	11·73	s. s.	9·91	0·40	9·00			1·6	9·37	4·7	8·68	31	Grey	
" "	"	1738	18·	4·		0	17·74	0·3	15·78	3·00	10·30			5·0	3·26	2·6	5·45	13	Grey	
Rusty shale, "	"	1739	15	3·		·2	14·41	1·0	13·02					2·7	9·55	1·7	9·48		Buff	
Surface clay, Hazel Brae	"	1740	22	4·4		1·0	16·75	9·0	2·12	9·3	1·0	9·4	1·00						Red	
Clay under coal, Collins gulch	"	1741	30	6·3		·3	18·63	2·6	13·14									2	Red	
Surface clay, Tulameen	"	1742														8·0	7·00		Grey	
Boulder clay, Riverside	Alta.	1743	25	5·6		s. s.	17·24	5·8	4·57										Red	
		1744	19·	6·9		·2	11·65	4·4	3·12	2·4	1·45							5	Red	

Abbreviations.—s. s., slightly swelled. Vit., vitrified.

SOME FEATURES OF REPLACEMENT ORE-BODIES AND THE CRITERIA BY MEANS OF WHICH THEY MAY BE RECOGNIZED.

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(Annual Meeting, Toronto, 1910.)

I.—INTRODUCTION.

Historical Review.—Of recent years our ideas concerning many phases of the formation of deposits of the ores of the metals have made rapid advances. Many of the processes involved in the formation of such ores have been made much clearer by careful investigation and study. We have in this way come clearly to understand that the most fundamental distinction in the larger grouping of metalliferous deposits is that between those which have been formed contemporaneously with the enclosing rock and thus are part and parcel of it, owing their origin to the same set of processes which have produced the rock itself; and those which have in some way been introduced into the country rock after (and generally long after) its solidification in the form in which we now know it. To the first group the term "syngenetic" has been applied, to the second, "epigenetic," words which may be translated into simpler language as *contemporaneous* and *subsequent.* With the second, or epigenetic group, this discussion is entirely concerned.

In epigenetic deposits the constituent minerals are known beyond question to have found their way to the places where we find them since the enclosing rock has assumed the condition in which we find it. If the enclosing rock is an eruptive, as granite, it was a granite in all essentials as it now exists *before* any mineral deposit was formed in it. If a sediment, it was an already consolidated rock, be it limestone, sandstone, shale or other sediment, before it was invaded by the agents which formed the ores we find in it.

In order to find a resting place in solid rock masses, metalliferous ores must in some way gain an entry into the rock. Either the space which they now fill must have been ready for their entry at the time of deposit, or the rock material must have been in some way expelled to make room for them. Posepny has expressed this self-evident fact most admirably.[1]

"With relation to the xenogenites, epigenetic or mineral deposits, the first question concerns the space which every secondary mineral or mineral-aggregate requires to establish its existence. It must either have found this space waiting for it, or it must have made room by driving out an original mineral."

In all of the earlier years of the study of ore deposits the space was generally considered to have first existed in the rock, forming a receptacle in which the deposition of foreign mineral substance could go on. Fissure veins, being long tacitly regarded as the prevailing type of epigenetic deposit, did much to strengthen this view. Deposits now believed not to be cavity fillings were little understood, and attempts to explain them always found expression in terms of cavity fillings. The classification of ore deposits depended, for suggested divisions into the several groups, largely on the form of the cavity which received the deposit. When disseminated particles of mineral foreign to the country rock were found in the rocks adjoining fissures, or in large disseminated masses about little cracks, they were called impregnations and were regarded as pore spaces in the rock which had been invaded and filled with ore, which migrated to limited distances from the conduit and filled pre-existing spaces in the rock. No account was taken of the facts now known, that the porosity of some rocks in which such impregnations are found, as for instance the granites adjoining the tin veins of Cornwall, where such deposits are called *Carbonas* was less than the volume of the minerals introduced into the rock.

[1] Genesis of Ore deposits. Trans. of the Am. Inst. of Mining Engineers, Vol. XXIII, p. 207.

Great irregular masses, wholly enclosed in limestone, such as those at Leadville, Colorado, Eureka, Nevada, and elsewhere, which were evidently epigenetic in character, but had not found simple fissures for a resting place, were explained as filling spaces of dissolution, *i.e.*, caverns in the limestone which had been dissolved out by percolating waters, caverns which had their analogues in the Mammoth and Wyandotte Caves in Kentucky and Indiana.

The words of Arnold Hague as late as 1891[1] relating to the great irregular deposits of Eureka, Nevada, are interesting in this respect:

"A study of these channels and their intricate connections tends to the belief in the theory of pre-existing caves and underground water courses before the introduction of ore. . . . . it is most difficult to see how such vast accumulations of these sulphides could have been formed in any other way than in the pre-existing caves and openings. Any theory with which we are acquainted of chemical and physical replacement of the limestone or dolomite seems wholly inadequate to meet the necessary conditions. Pseudomorphs of galena and pyrites after calcite have been described as mineralogical curiosities and possibilities, but nowhere have they been found in large quantities in any mine, and, so far as the writer is aware, they have never been recognized at Eureka. . . . They (*i.e.* the ores) were for the most part deposited as sulphides in pre-existing caves and cavities."

Newberry writing in 1880,[2] says:

"These (the Leadville ore-bodies) undoubtedly accumulated in vacant spaces formed by the solution of the limestone."

At this stage, the idea which had suggested itself long before with relation to the siliceous casts of fossils, silicified wood, etc., began to be applied to the formation of ore deposits. It had been recognized by mineralogists for many years that crystals of one substance could be altered chemically into a mineral of wholly different chemical composition and still retain the form of the original mineral. Such crystals were called pseudomorphs, and certain of them could be shown to have resulted, not from a solution of the first mineral and a refilling of the space with the secondary mineral, but by a gradual molecular substitution of one substance for another. Lindgren[3] has cited the various classifications of pseudomorphs proposed, so that at this point they need not be repeated.

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[1] Hague: *Geology of the Eureka District, Nevada*, Mon. XX, United States Geological Survey, 1892, pp. 308, 311, 316.

[2] "*On the Origin and Classification of Ore Deposits*," School of Mines Quarterly, Vol. I No. 3, p. 92. March 1880.

[3] Lindgren, Trans. Am. Inst. Min. Eng. Vol. XXX, pp. 581-584.

From its application in the case of a single mineral the process of molecular substitution was then applied by geologists and palæontologists to fossils composed of separate mineral grains. The pseudomorphism in this case was a retention of the form and internal structure of the fossil rather than of its individual crystalline grains, though the passage from a single crystal to an aggregate of crystals was simple and involved no new supposition. Archibald Geikie,[1] writing in 1882, gave an admirable statement of the process as applied to fossils. (See pages 440-441 of this paper.)

The application of this process to ore bodies did not, however, proceed as rapidly. Emmons has shown [2] that Charpentier had distinctly formulated the theory of replacement as early as 1778, but that, like many opinions expressed without evidence, it was unnoticed and seems to have been disregarded for many years.

Pumpelly was the first to apply it in the United States to the copper deposits of Lake Superior in 1873.

In 1886 it was applied by Emmons to the ore-deposits of Leadville, Colorado.

In 1887–8, it was applied by Irving and Van Hise to the formation of the iron ores of Lake Superior region in the Penokee Gogebic range. Surface waters were here described as descending until contact with impervious beds caused their accumulation and stagnation and ore was formed by a substitution of iron oxide for country rock.

In all of these cases it was asserted that no open space had ever existed other than that necessaiy to permit waters to gain access to the rock affected; that ore-bodies, grew in rocks by the gradual replacement of the material by the new substance taking its place. An interchange of metallic sulphide or gangue mineral for country rock was supposed to have taken place. The process by which this occurred was considered chemical, and in a measure akin to the replacement of one crystal by another with retention of the form of the original, known under the general name of *pseudomorphism*. The process was correlated with pseudomorphism only in a vague way, and was termed replacement, substitution, metasomatism, metasomatic interchange, etc.

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[1] Text Book of Geology, 1st edition, 1882, p. 610.

[2] Emmons, S. F., "Theories of Ore deposition historically considered." Eng. and Min. Jl, Vol. 77, p. 119.

The idea once formulated, and here and there definitely stated to have taken place, gained ground rapidly, and up to 1900, was applied to the formation of many ore deposits in limestone and also in many other types of rocks. Like nearly every new idea which explains natural phenomena not previously understood, origin by replacement has been eagerly applied to a vast concourse of deposits, some of which probably had such an origin and some of which undoubtedly did not, as subsequent careful investigation has proved. The pendulum of thought, indeed, at one time swung so far to the side of replacement that some geologists questioned whether banded fissure veins might not have been, in nearly all cases, formed almost entirely by replacement.[1]

A more conservative attitude of mind has now followed, and the rôle of replacement as an ore-building process is applied with more care to only those ore bodies to which no simpler explanation is applicable.

Until 1900, no attempt was made to definitely formulate any correlation between metasomatic processes of ore formation and pseudomorphism, or to present the subject in any connected paper dealing with the process in general. In that year however, (1900), Mr. Waldemar Lindgren published a paper in the Transactions of the American Institute of Mining Engineers,[2] entitled "Metasomatic Processes in Fissure Veins." In this essay the chemical and physical nature of the processes involved in the alteration of vein walls are discussed with such clearness and precision that economic geology owes to him for this masterly treatment a debt of gratitude which cannot be overestimated.

It will seem to those who have studied this paper that there is little to be added to what Mr. Lindgren has so clearly presented. In many respects this is true, and the writer will have occasion to refer frequently to Mr. Lindgren's work; but it must be remembered that his paper deals chiefly with fissure veins in which metasomatic processes have formed ore bodies that are essentially subordinate in importance to the fillings of cavities through which the replacing solutions have circulated. He was also especially concerned with the mineral changes of vein walls; that is, his paper was chiefly mineralogical and chemical. It is not the pur-

[1] Emmons, Trans. Am. Inst. Min. Engs., Vol. XV, p. 123.
[2] Tr. A. I. M. E., Vol. XXX, pp. 578-692.

pose of this paper to enter into such a detailed discussion of the chemical problems of replacement, but rather to describe some of the characteristic features of replacement deposits and to attempt to establish some criteria by means of which the effects of replacement may be recognized. It will also be concerned chiefly with those ore-deposits in which replacement has been the preponderant process and cavity filling has been only subordinate. As such deposits are more common and larger in limestone formations than elsewhere, the paper will, of course, deal more largely with them than with other types.

It may be urged as an additional warrant for a presentation of certain phases of this important subject that some criticism has recently been urged against it. One or two geologists believe, for instance, that it is often, if not nearly always, applied when an appeal to it is not only unnecessary but misleading.

II.—FORMS AND DIMENSIONS OF REPLACEMENT ORE-BODIES.

General.—Ore masses formed by replacement are characterized by great variation in size and a bewildering variety of different forms. As they are independent of open space available for free deposition, the size which they may attain is subject to no definite limits. They range from narrow mineralized borders forming penumbral margins around the edges of filled rock cavities to huge masses which equal or exceed in their dimensions nearly all other types of ore deposits. Those which are formed by the replacement of massive limestones are especially apt to attain great size, presumably on account of the facility with which the process goes on in this especially soluble rock. Although their great irregularity precludes any very exact estimation of volume, the following table, giving the approximate maximum dimensions of some well known occurrences, will serve to convey some idea of the magnitude of some of the ore masses formed in this way:

	Length	Width	Thickness
Henriette—Wolftone—R.A.M. Shoot Leadville (ox and sul)	3,000 ft.	1,600 ft.	200 ft.
Moyer Main Shoot (sulphides) Leadville...	2,340 "	1,300 "	150 "
Gold Ore Shoot (oxidized ore) Leadville...	3,000 "	400 "	240 "
Greenback Shoot (sulphides) Leadville.....	350 "	500 "	300 "
Eureka Nevada*......................	400 "	150 "	100 "

* The Eureka ore-bodies are so extremely irregular that any exact measurements are impossible. These dimensions are measured on the "800 ore body," Plate III, Mon. VII, U. S. Geol. Survey.

COPPER QUEEN ORE-BODIES.

I.	600 ft.	250 ft.	150 ft.
II.	600	830	100
III.	500	225	150

The first impression gained from a comparative study of the collected plans and sections of replacement ore-bodies is that of great variety and extreme irregularity of form. The series of typical plans and sections from Leadville, Bisbee, The Black Hills,[1] etc., show the extremely intricate and complicated shapes which these masses frequently assume. A more careful study, however, both of these plates and of the actual occurrences in the field serves to show that nearly all of these intricacies of form are referable to some well defined cause or causes and that the complex shapes are not in any sense fortuitous. The causes producing these features are so simple that their statement seems hardly necessary; but that the general discussion of the subject may be clearer to those who have not had opportunity to observe this class of ore-bodies they are here separately stated.

The shape of a replacement ore mass is due to the following causes:

1. Relation to channels of access of ore-bearing solutions.
2. Variations in chemical character and structural arrangement of enclosing rocks.
3. Manner in which mineralizing waters have affected the rock.
4. Amount of material supplied in solution.

Relation of Ore-Bearing Solutions to Channels of Access.

The most important factor influencing the form of an ore mass formed by replacement is the channel or opening which has admitted the ore-bearing solutions to the rock mass which has been replaced. No substitution of ore for country rock can, of course, occur unless solutions have first been able to reach the rock susceptible to replacement.[2] The openings which occur in

[1] Plate I, Figs. 1, 5, 6, 11.

[2] Exception is of course to be made in the case of contact metamorphic ore-deposits when ore-bodies develop in the neighborhood of intrusive igneous masses which have themselves yielded the solutions for the mineralization of the adjacent rock. Such deposits may form without the pre-existence of cavities.

rocks are of many different kinds and it is, of course, possible for replacement to be initiated from any of them irrespective of their form or origin; joint cracks, fissures, large faults, brecciated zones, horizontal spaces between separated strata, vesicular cavities, intergranular spaces, etc., serve equally well as starting points for the process. All of these forms of rock openings undoubtedly serve as initial points for replacement; but those which are of comparatively small size and are discontinuous have simply permitted the extension and easy penetration and mineralization of a susceptible rock mass, and cannot be regarded as the conduits or main channels of access. To serve as adits or connections between susceptible rock masses and deeper seated sources of mineralizing waters cavities must be continuous for considerable distances. They must be trunk channels of some kind. That a susceptible rock should be porous, open textured, brecciated, jointed, etc., is an aid to mineralizers once they have reached the rock affected, but is insufficient in itself to afford access to mineralizers. It therefore happens that replacement ore-bodies are generally found associated with some form of fissures in the country rock which are either singly or collectively capable of conducting solutions from considerable distances to the locus of deposition. There are few, if any, instances with which the writer is familiar which do not permit either the actual observation of these fissures or their inference from the form and distribution of the ore masses. In the siliceous gold ore shoots of the Black Hills, South Dakota, they can be actually observed in the shale roof of the ore-bodies, sometimes as single fractures, sometimes as sheeted zones (see plate II), sometimes as broad zones of intersecting fracture. In Leadville they are observable in some cases extending downward from the ore-bodies into the granite underlying the susceptible rock series as fissure veins of considerable width, or they may be inferred from the regularity of trend of the shoots when plotted on a map (see fig. 5) Iron Hill Shoots. The absence of fissures beneath many of the large ore-bodies of this region is probably due to the facility with which limestone rocks become recemented after rupture.

In the case of fissure veins with limited amount of replacement along the walls the channel of access is so very much more

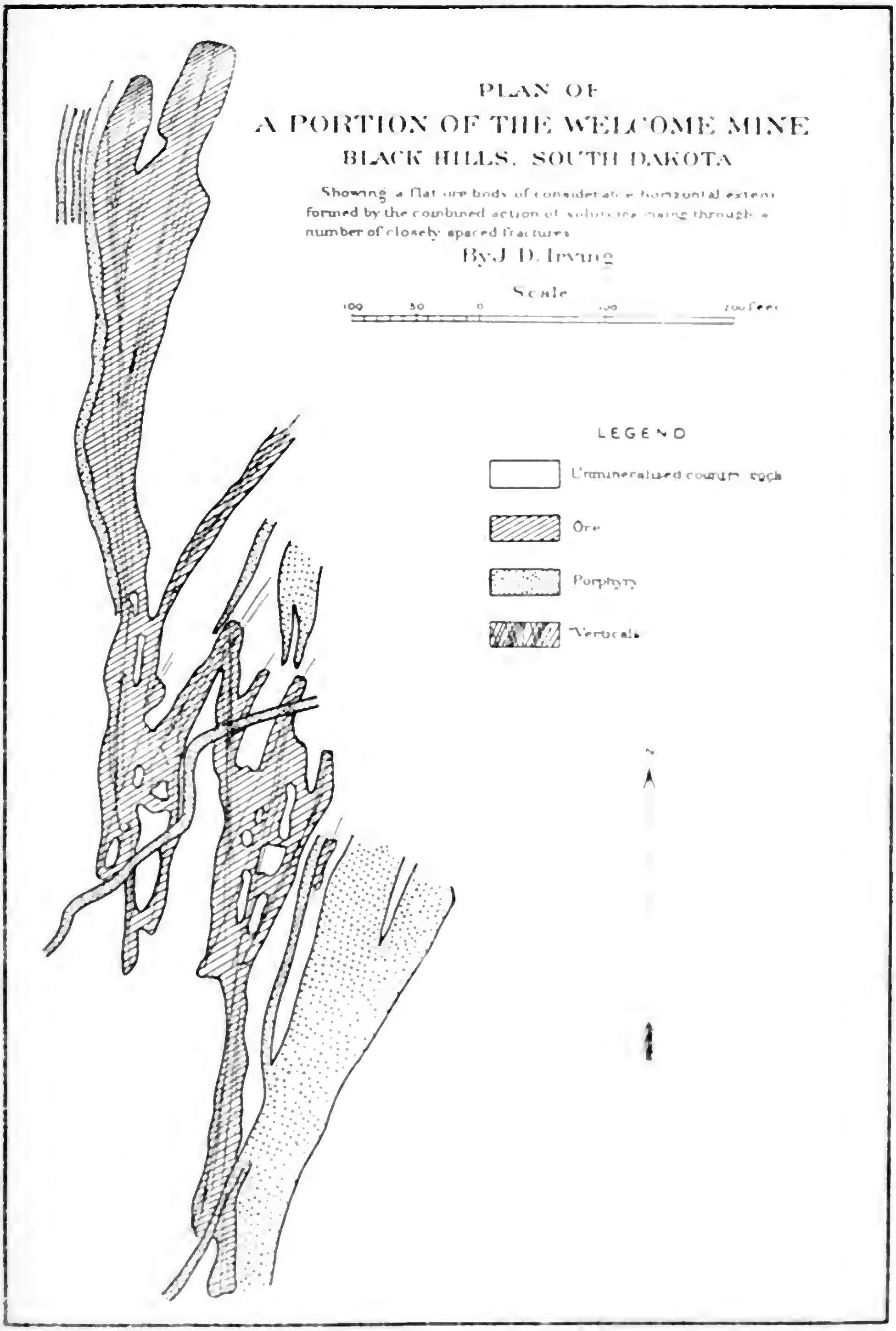


PLATE I.—Plan of the ore-shoots of the Welcome Mine, Black Hills, South Dakota, showing the manner in which the ore is associated with fissures or "channels of access" and the occurrence of isolated islands of unmineralized limestone within the ore mass. (After Irving, U. S. Geol. Survey, Prof. paper No. 26, Plate XIII.)

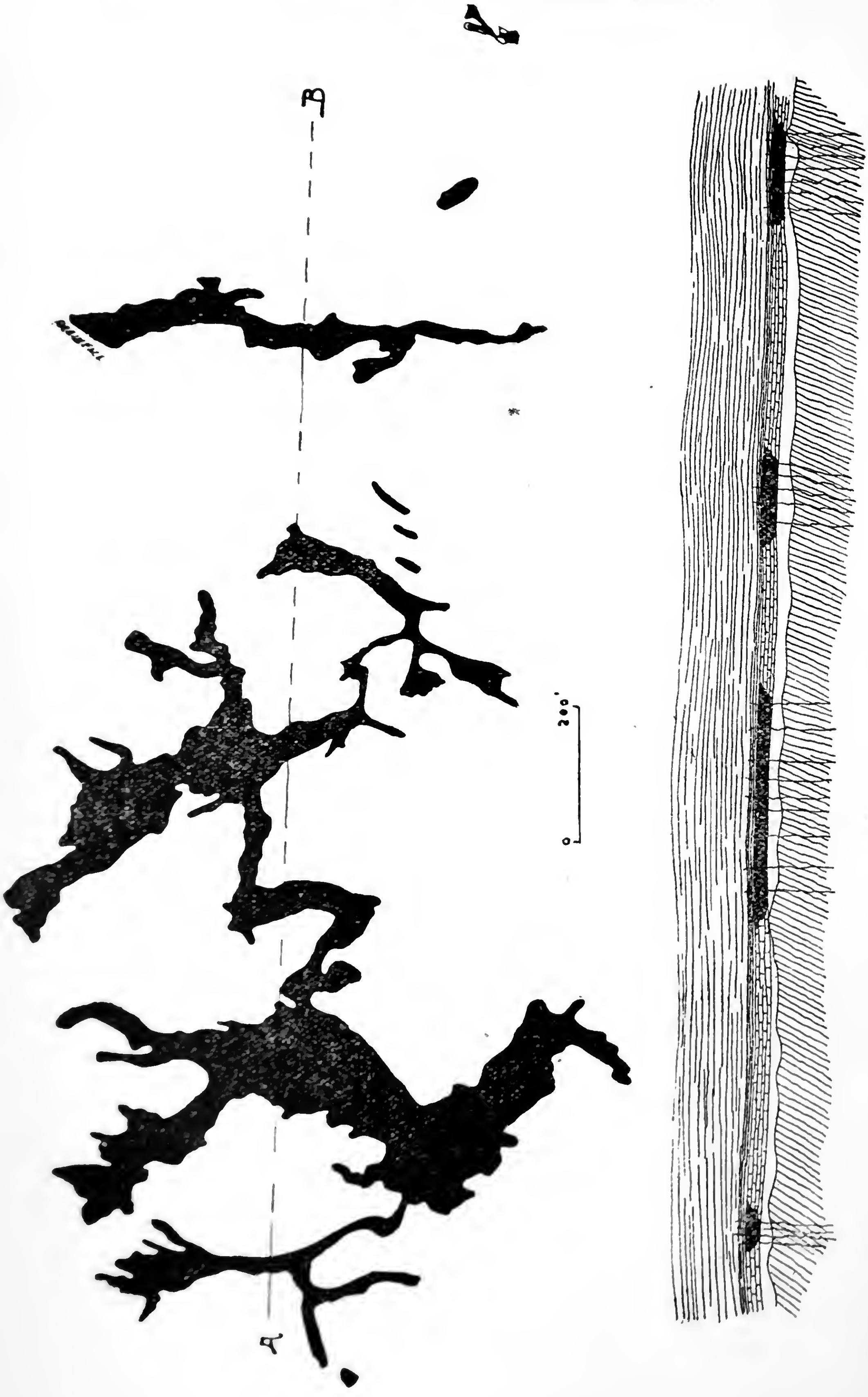


FIG. 1.—Plan and partial section of the ore-shoots of the Penobscot Mines, Garden City, Black Hills, South Dakota. Shows the relation of the form of the ore-bodies to "channels of access" and manner in which small off-shoots form on single fractures which run out into the rocks from the main fractured zones. From the published report of the company.

prominent than the replacement mass arising from it that there is no possibility of doubt as to opening from which the mineralization started.

When solutions have once gained access to rocks susceptible to replacement, joint cracks, rock pores, brecciated structures, stock-works and other smaller and less continuous openings, by affording easy circulation and increasing the available surface for chemical action, greatly facilitate and accelerate the process.

Forms due to Single Fissures.—Where replacement has proceeded from a single fissure *intersecting a homogeneous* rock, the form of the resulting replacement mass usually is tabular. Its boundary will sometimes be extremely indefinite, the new minerals becoming more and more sparsely scattered as one passes outward from the conduit which admitted the solutions until the ore passes insensibly into country rock. At other times it will be extremely sharp, so that the passage from ore to country rock is abrupt. (See fig. 2, A and B.)

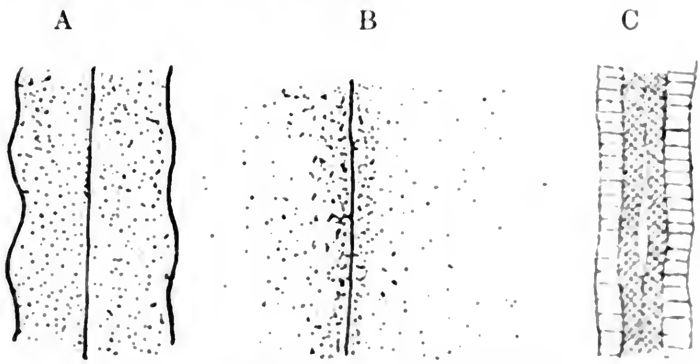


FIG. 2.—DIAGRAMMATIC SKETCHES.

A—Shows how replacement which arises from a single fissure is sometimes sharply separated from the unmineralized rock.
B—The same relation to a fissure, but fading gradually into the country.
C—Filled fissure.

In all cases, however, the boundary, though as a whole tabular, will rarely be parallel in detail to the wall of the channel of admission, and irregular apophyses will run outward from the main replacement mass where solutions have, for some reason, operated more extensively than in other places. In some cases, as at East Huell Lovell, Cornwall, England, the rock along some one portion of an opening has been more extensively attacked than at others. A lenticular mass is then produced. (Fig. 3.)

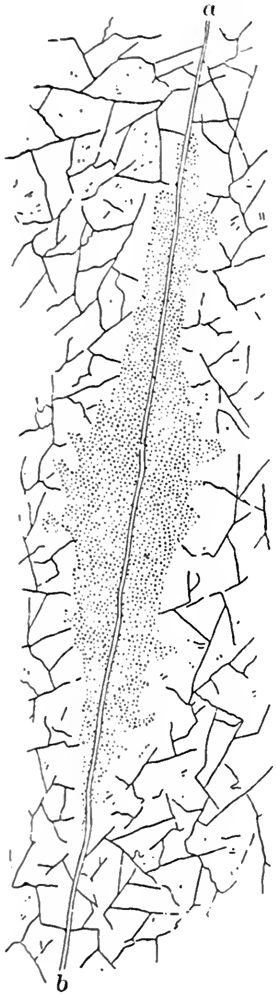


FIG. 3.—Horizontal section of carbona on the 100 ft. level of East Huell Lovell, Cornwall. Width at widest point, 9 feet. Shows how rock along one portion of channel is extensively replaced and elsewhere more slightly.

It is often difficult to determine, where fissures intersect homogeneous rock masses, why some portions of the wall rock have been extensively attacked and others scarcely at all; but it is frequently the case. Possibly a slightly greater porosity, or the absence of intervening layers of impermeable selvage clay, or a slight difference in the composition of the original rock may have determined it, or the constriction of the fissure above the most extensive replacement mass may have permitted the stoppage and stagnation of the solutions and afforded them more time in which to affect an interchange of new for old minerals.

In some cases such replacements are a symmetrical laterally and a selvage clay on one side has prevented replacement so that the rock on the other only has been attacked.

The distance to which replacement may extend from a single channel varies greatly. In compact rocks like granite it isusually small, perhaps, not over 4 or 5 feet. Again in the Cambrian limestone in the Black Hills, the distance is not very great, possibly not over 10 to 15 feet. In the more permeable limestone in the Neodesha mine near Ouray it extends for more than 100 feet. Such a great extent from a single fissure is exceptional, especially where the fissure is in homogeneous rock, all portions of which are equally susceptible to replacement.

When viewed in plan, shoots arising from single fissures are seen to have a roughly lenticular form, the widest portion being at that point where the supply of mineralizing water was present in greatest amount. (See fig. 3.)

Forms due to Multiple Fissuring.—If all fissures were widely spaced, single openings, it is probable that replacement masses would show little variety of form other than that which will be later described as due to the chemical composition and structual arrangement of the rocks intersected by the opening. Fissures are, however, notably variable in their position and relation or one another. They rarely occur alone, but rather in parallel to intersecting groups or systems. Where more than one fissure or opening occurs nearer to another than the distance to which replacement may proceed, the replacement mass arising from one fissure coalesces with that proceeding in the opposite direction from the fissure next adjoining, and a large mass of ore is thus produced.

It is then obvious that the larger features of the form of a replacement mass, that is, the form as a whole, in a homogeneous rock will be determined by the distribution and spacing of the openings. If viewed in section and plan fissures may be arranged (1) in parallel groups, (2) in intersecting groups.

Parallel Groups. Lode Fissures.—Parallel fissures accompanied by extensive replacement give rise to what may be conveniently termed *lode fissures.*[1] Where rocks have been fissured and faulted it often, indeed generally, happens that the opening

[1] These are termed by Emmons *replacement* veins. See text accompanying Butte Special Folio, U. S. Geol. Survey, Folio No. 38.

is not a single fissure. The movement is distributed along a series of parallel, closely spaced fissures, usually of very small width, which include between themselves narrow, tabular plates of country rock. These fissures are most frequently closely spaced along the centre of the zone, *i.e.*, the plane of maximum movement, but separated by wider and wider plates of country rock in either direction. Such groups of parallel fissures are generally termed "sheeted zones." Solutions entering such a series of parallel fissures often replace the narrower plates completely and result in a solid tabular mass of ore in which the traces of the original fissuring produce a banded structure not unlike that caused by true crustification. Fig. 4 below illustrates a fissure of this kind.

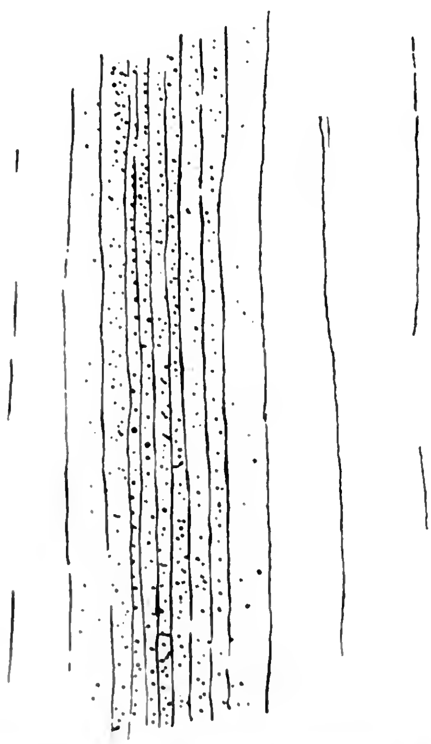


FIG. 4. Lode fissure formed by the replacement of plates of rock in between multitudes of parallel fractures. Fissures decrease in number from centre of disturbance outward.

It sometimes happens that in lode fissures of this kind the central portion only of the lode is a solid mass of ore. Beyond this central zone the individual fractures are separated too widely to allow the mineralization arising from adjacent fissures to coalesce. The main lode is thus often separated by a plate or wall of barren rock from narrower parallel side lodes and important and commercially valuable veins not infrequently overlooked owing to a failure to understand the origin of the vein.

In horizontal projection lode fissures of this kind differ little if at all from normal fissure veins, into which, indeed, they pass by imperceptible gradations when the open space increases in amount and the replacement of the walls extends to less distances into the adjacent rock.

Intersecting Groups.—Intersecting fissures divide the rock masses which they intersect, into groups of polygonal angular blocks. The form of replacement bodies arising from such systems depends chiefly upon the closeness of the spacing. If the fissures are wide apart the polygonal blocks of country rock which intervene are larger than the width of the replacement body arising from any single fissure and a series of replacement ore bodies results both in plan and section which is no more than a group of single fissure replacement shoots intersecting one another. Figs. 5 and 6 illustrate this.

The intersections of such shoots are rarely angular, for the solutions round off the narrow points between the intersections and often produce a larger and more irregular mass than along that part of the fracture which is further removed from the point of intersection. When fissures are more closely spaced, so as to form stock-works, they are often nearer together than the distance to which replacement arising from a single fissure may readily extend and the entire rock mass is replaced with its outer limits determined by the limits of the fractured portion of the country rock. As movements which result in the rupture of rocks generally occur along lines or linear zones whose longer diameter is very much greater than the distance across the fractured zones, such ore deposits are generally linear, i.e., very much longer than they are broad. The presence of stockwork-like fissures can be readily detected in such masses at their edges as there the fractures are fewer in number and run out into the unmineralized rock. The replacement shoots arising from them also run out into the country, forming a peculiar fringe of little offshoots or apophyses which by their parallel arrangement disclose the presence of the fissure systems which have given rise to them.

Fig. 5.—Plan of ore-shoots on Iron Hill, Leadville, Colorado (after A. A. Blow, Am. Inst. of Min. Eng., Vol. XVIII, p. 180, Plate I. Corrections and additions made by writer.) Shows great size of shoots, irregularity of outline in detail and evidence of formation along zones of fissuring.

In massive rocks, like heavy bedded limestones, the fracturing of the rock is often so irregular that the polygonal blocks which intervene between individual joints have very complicated forms and the resulting ore masses are characterized by the most extraordinary and intricate form. Fig. 6 will illustrate this.

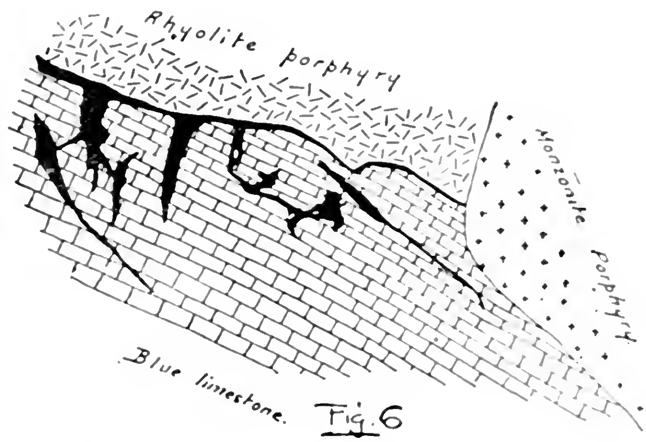


FIG. 6.—Cross-section of the ore-shoots of the Oro La Plata mine, Leadville, Colorado, showing the extremely irregular character of the ore-shoots formed along irregular fractures in the Blue Limestone. Scale, 240 ft.=1 inch.

When multiple intersecting systems of closely spaced, minute fissures intersect rocks more resistant than limestone, as in the Treadwell mine in Alaska, the replacement extends to only very short distances from any single fissure and yet the resulting mass through which the ore is disseminated is of very great size.

Minor irregularities of outline.—In addition to the larger features of form which are more or less directly referable to the distribution and arrangement of fissures, there are many detailed irregularities of form which are independent of the direction and position of the fissures from which waters have operated. When solutions migrate outward from a fracture they replace the rock to varying distances, so that the surfaces of demarcation between the outside edge of the ore mass and the unaltered country rock are rarely, if ever, parallel in detail to the opening from which the solutions originated, but are curved and wavy surfaces. While these surfaces are in some cases roughly parallel to the fissure and only irregular in their more minute details, in others they extend out in "pipes" or apophyses, which wander without regularity of direction for often considerable distances beyond the main body of the ore and form a mass whose outlines are frequently bewilderingly complex. Between these two extremes all gradations occur.

Figs. 7, 8 and 9 will show this irregularity, which is often noticeable in the detail of the lines of demarcation between ore and rock. In these specimens the boundaries are sharp and do not, as is often the case, fade off gradually into the surrounding rock.

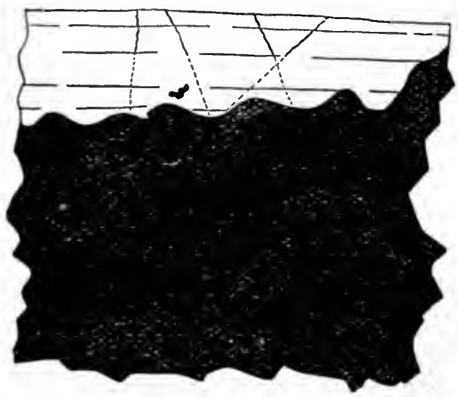


FIG. 7.—Galena block replacing limestone from Leadville, Colorado, showing wavy line of demarcation between galena (black) and limestone (white). About half natural size.

In some cases long pipe-like arms, roughly circular in cross section, wander outward, twisting and turning as they go for sometimes as much as 30 or 40 feet away from the main mass and apparently independent of any perceptible opening. One of these is shown in Fig. 10.

Apophyses of this kind are often difficult to explain. They are probably due to differing porosity in the areas replaced; but no comparison can be made of the rock replaced with that unaffected, as it has all now been altered to ore. Care must be taken not to confuse irregular arms and apophyses of ore of this kind which are independent of any auxiliary fissure with "pipes" of ore such as those in the Yankee Boy and Guston mines[1] near Silverton, Colorado. The latter seem to have been formed along

[1] T. E. Schwartz, T.A.I.M.E., Vol. 26, p. 1056.

FIG. 8.—Wavy line of demarcation between ore (dark) and limestone (light) from siliceous ore on Dacy Flat, Ragged Top, Black Hills, South Dakota. The general direction of the supplying fissure is about parallel to the right hand edge of the specimen. About quarter natural size.

FIG. 9—Specimen of siliceous ore from Penobscot mine, Black Hills, South Dakota. Shows wavy lines of demarcation between ore (dark) and limestone (light). About half natural size.

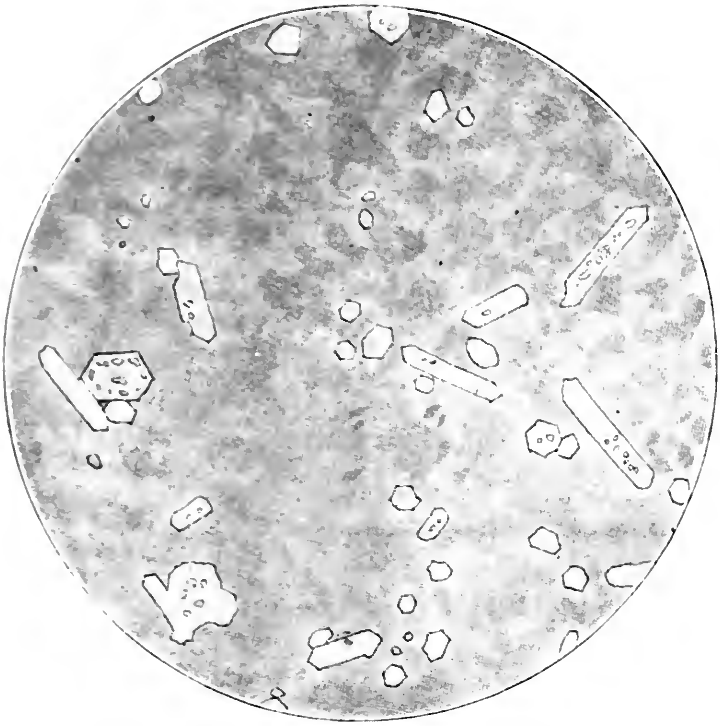


FIG. 19.—Incipient silicification of limestone, Aspen, Colorado. White areas represent quartz crystals with small inclusions of limestone. Magnified 30 diameters. (After Lindgren, T.A.I.M.E., Vol. XXX, p. 628). This is the nature of partly replaced rock when the process has been arrested before it was completed.

FIG. 20.—Silicified limestone ("Jaspeorid"), Aspen, Colorado, Cross Nicols. All quartz. Small inclusions of calcite in some of the grains. Magnified 30 diameters. (After Lindgren, T.A.I.M.E., Vol. XXX, p. 628). This shows the process completed. Complete outlines of earlier formed, automorphic crystals are seen in the later replacement silica, which is xenomorphic.

what Schwartz terms "ore breaks," that is, channels of easy flow along intersections of sheeted zones or fissure systems.

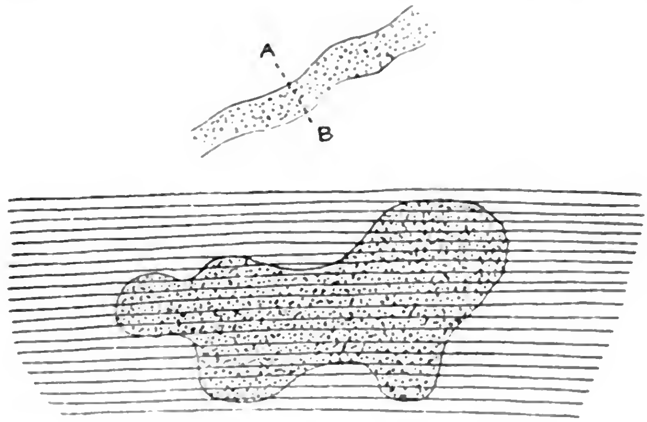


FIG. 10.—Plan and cross-section of long, irregular arm of ore, which runs out from the main body into the stratified limestone, and preserves the sedimentary banding of the limestone in the ore. Scale of section 10 times that of plan. Portland mine, Portland, South Dakota.

The apophyses here described are merely irregularities in detail of the *free faces*[1] of masses, which are in general easily referable to some fissure in the country rock and are rarely of large dimensions unless some auxiliary fissure or opening in the rock has determined their form and extent. Fig. 11 shows both classes of detail at the edges of a single ore body.

VARIATIONS IN CHEMICAL CHARACTER AND STRUCTURAL ARRANGEMENT OF ENCLOSING ROCKS.

Fully as important in determining the shape of replacement masses is the chemical character and structural arrangement of the enclosing rocks.

Fissures do not, of course, occur exclusively in homogeneous rocks, or in rocks composed of grains of one mineral only. They frequently pass through rocks of widely varying lithologic character or rocks that, although as a whole homogeneous, are made up of aggregates of different minerals which have widely different susceptibilities to replacement processes.

Forms produced in Rocks composed of Different Minerals.—When rocks are mechanical mixtures of different minerals some

[1] See page 416 for definition of term *free face*.

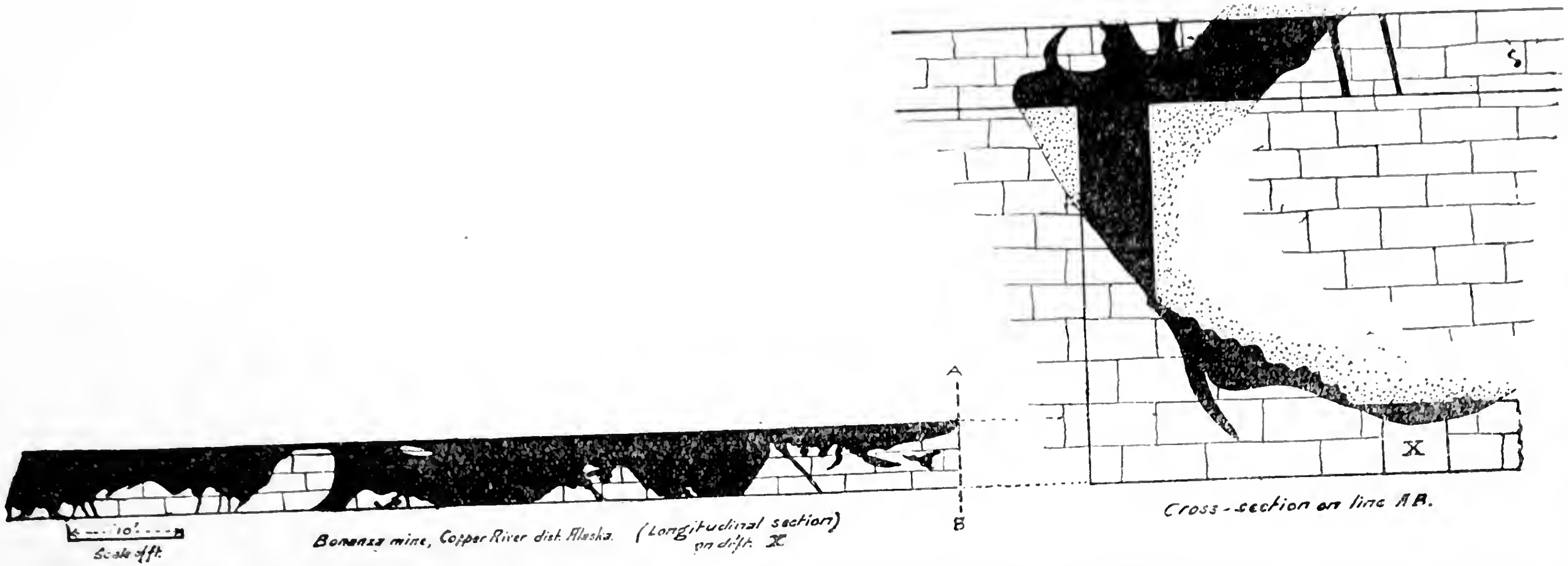


FIG. 11.—Plan and section of tunnel and winze in Bonanza mine, Chitina River copper district, Alaska. Shows a large body of almost solid chalcocite replacing limestone. The irregularity in detail and the partial relation of this irregularity to fissures is indicated very clearly in these sections. Scale of both sections is the same.

minerals will be more resistant to chemical alteration or replacement than others. Thus, in a calcareous sandstone composed of grains of sand cemented together by calcite, the calcite will be readily replaced; but the more resistant quartz left without alteration. In a granite which is composed of feldspars, muscovite and quartz, the feldspars may suffer replacement and the quartz and mica remain unaffected. It therefore happens that rocks of this kind when affected by any given solution will often be but partially replaced and that the ore resulting from the process will be disseminated through the mass in much the same attitude as the original susceptible mineral.

A calcareous quartzite of this kind has been transformed into ore in some of the silicious ore districts in the Black Hills, the cementing calcite only having yielded to mineralizing processes. This disseminated type of replacement deposit where only the favourable minerals of the rock have been replaced is especially common in the case of igneous rocks. The edge of such masses are rarely sharp, but almost always fade gradually into country rock and rarely if ever present the sharp boundaries which are so often found in rocks which are replaceable as a whole.

Forms produced by variation in Structural Arrangement of Rocks.—When fissure channels of access pass through rocks of differing susceptibility the more susceptible rocks are usually replaced to greater distances than the unsusceptible, and the resulting form is then tooth-shaped and depends upon the shape and extent of the susceptible layer more than upon the direction and position of the fissures. This is especially noticeable where fissures intersect alternating layers of sedimentary rocks of different chemical composition, such as limestones, shales and quartzites. The limestones will usually be extensively replaced and the other rock layers only slightly. If only one especially susceptible layer is present and is of limited thickness it is frequently replaced completely from underlying to overlying insoluble layer and the result is a bedded deposit with irregular boundaries only where the end of the replacement mass crosses the replaced bed. Elsewhere it is evenly and often conformably bounded by the adjacent insoluble strata. In plan the forms of bedded masses such as this are determined by the fissures or fissured zones along which they extend. An excellent illustration is that given in Fig. 1 (see page 12), where the bedded form due to the position and thickness of the original limestone layer is admirably seen in cross section, and the irregular outlines and evidence of intersecting fissure systems are seen in the plan.

Another illustration where the fissure is relatively wide and the replacement bed extends for only a short distance away from the fissure is shown in Fig. 12.

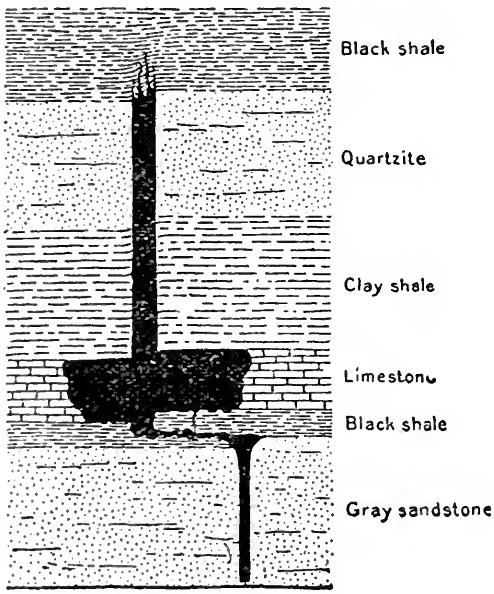


FIG. 12.—Cross-section of vein near Ouray, Colorado. Shows a fairly wide fissure vein intercepting limestone beds with replacement shoot formed in the limestone and extending to 15 or 20 feet from the fissure on either side of the main vein. After Irving, Bull. 260, U. S. Geol. Sur.

If the replacement mass is smaller than the susceptible rock mass which lies between the impervious bounding rocks there will be a line of demarcation between it and the unreplaced portion of the susceptible rock which will have the usual wavy outline or will show gradual transition into country rock. For the sake of convenience this may be called the "free face." Plate II and Fig. 13 show plans and sections of the ore shoots from the Black Hills of South Dakota which illustrate the same feature.

It is easy to see why such masses as that shown in Plate II Fig. K were confused by early writers with sedimentary layers and why they are still included by many writers among the "bedded deposits" where the old classification by form is still in use. It would be exceedingly interesting to learn whether the much discussed and oft cited Mansfeld copper shales do not in reality belong in this group of flat conformable replacement deposits, which owe their form entirely to the position and chemical character of the replaced layer.

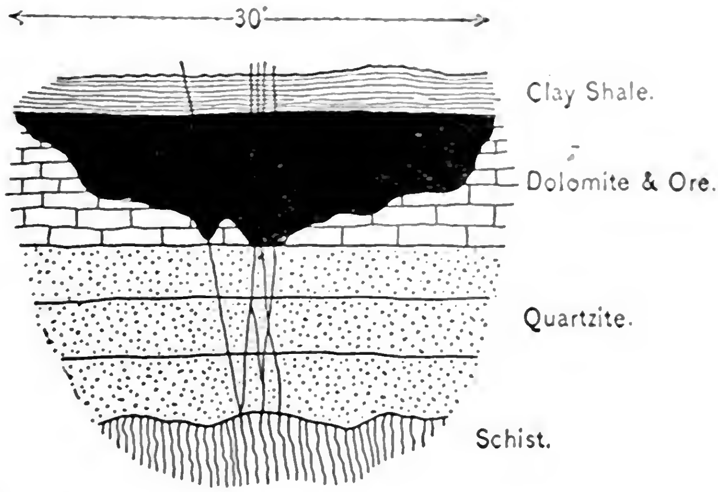


FIG. 13.—Form of shoot influenced by rock structure. Spread of ascending solutions on under side of impervious shales has made shoot wide at top and made a characteristic pear-shaped form. Scale, 25 ft.=1 in. Upper surface of ore is determined by adjacent impervious shales. The lower side is the "free face."

It is sometimes true that a replaceable bed or mass of limestone is entirely enclosed in a relatively impervious porphyry mass and that the entire rock mass has been replaced. This was the case in some of the Fryer Hill ore-bodies in Leadville. See Fig. 14.

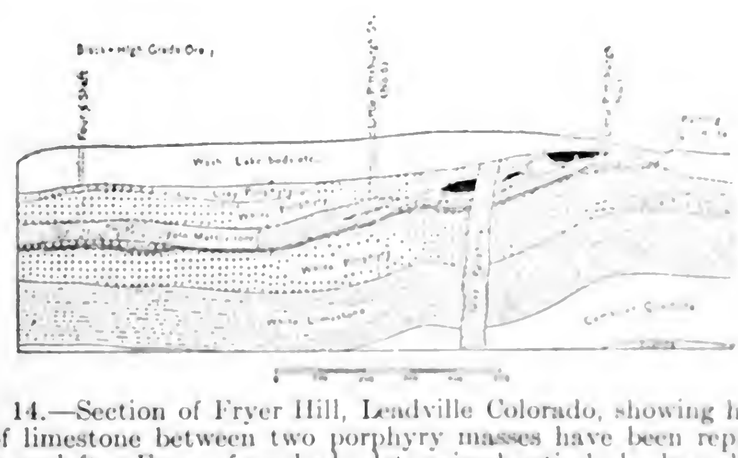


FIG. 14.—Section of Fryer Hill, Leadville Colorado, showing how entire masses of limestone between two porphyry masses have been replaced and no limestone left. Form of ore-body determined entirely by bounding rocks. There is no *free face*. (After S. F. Emmons, Mon. XII, U. S. Geol. Survey

As these were among the first ore-bodies studied by Emmons in Leadville he was naturally confronted by what seemed to be an extremely difficult problem, and it was only when he had seen the ore-bodies in the incompletely replaced rock that the origin of the ores by replacement of limestone became clear.[1]

When more than one susceptible layer is present, i.e., when susceptible strata alternate with resistant strata the resultant ore body will finger out into the surrounding sediments or even retain the unsusceptible layers throughout the entire mass. Such ore bodies have, in cross-section, saw-tooth forms or a sort of gridiron structure. An excellent illustration is given in Fig. 15 and also in Plate II-G. Masses of susceptible rock such as limestone may also be enclosed in irregular porphyry intrusions and may then have any form, so that the replacement will be confined to the susceptible rock, as in the Fryer Hill ore bodies just described and the resulting ore masses will have the same form as the replaced mass of rock.

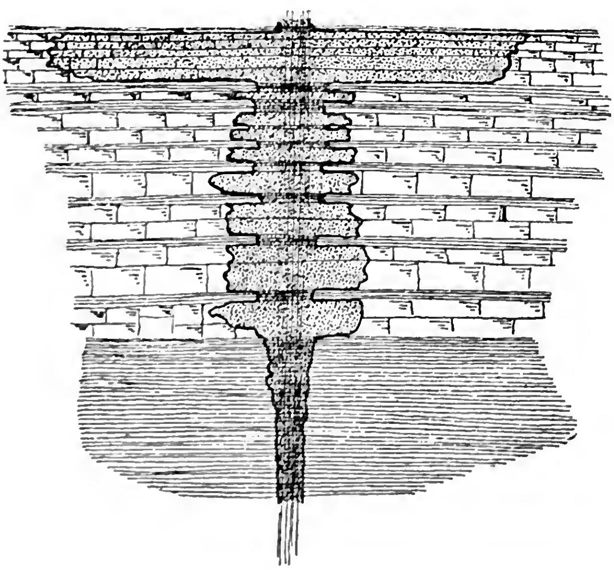


FIG. 15.—Cross-section of ore-shoot in alternating layers of shale and dolomite, Portland, South Dakota. The shales are only slightly replaced by silica, but the ore in the limestone layers runs out to greater distances from the fissure.

[1] Oral communication.

Effect of Impervious Barriers and Constriction of Cavities on Form.

Waters which circulate rapidly through natural conduits produce less replacement than those which move more slowly or come to rest, probably because more time is afforded for reaction with the surrounding rock than when circulation is rapid. It thus happens that if impervious barriers lie along the paths of fissures or rocks in which the fissures become lost or constricted, the solutions will be dammed up, spread out beneath or upon the impervious rocks and the mass of rock replaced at the point of stagnation will be very much greater than elsewhere. When waters are ascending (which is generally the case with primary ore masses) this stagnation is greatest *beneath* an impervious rock, shale, eruptive rock, etc., or *beneath* a rock which has fractured less readily and in which the fissures are comparatively constricted. The result is a large tabular mass roughly horizontal and with its greatest extent immediately below the barrier rock, and perfectly conformable to it but with a lower surface or *free face* which is extremely jagged and with long tongue-like apophyses running down into the soluble rock along the supplying fissures and fractures and finally dying out along them. Along a single fissure such deposits will often have a pear-shaped form in cross-section, such as that shown in Figs. 13 and 16. The impervious barrier in Fig. 16 is a heavy black shale and the replaced rock a quartzite. The fissures are shown in plan in Fig. 17. In this instance there are, in addition to the replacement masses in the quartzite, numbers of filled solution cavities and the ore masses themselves are usually surrounded by solution cavities which show all of the concave surfaces and other criteria so characteristic of openings formed by solution. The main ore masses, however, seem to have been formed by replacement.

Impervious barriers are effective in stagnating solutions not only when above or below the path of a fissure but also when they intersect it in a horizontal direction and even if parallel to the zone of fracturing. Thus in the Mineral Farm mine, a portion of which is shown in Fig. 18, a sheet of phonolite is intersected by a set of fractures which pass into it from the surrounding shaly limestone. The ore has completely replaced the rock adjacent to the phonolite; but has not connected the fissures at a distance of 50 feet from it. In the phonolite itself only a slight alteration a fraction of an inch from the wall has been produced.

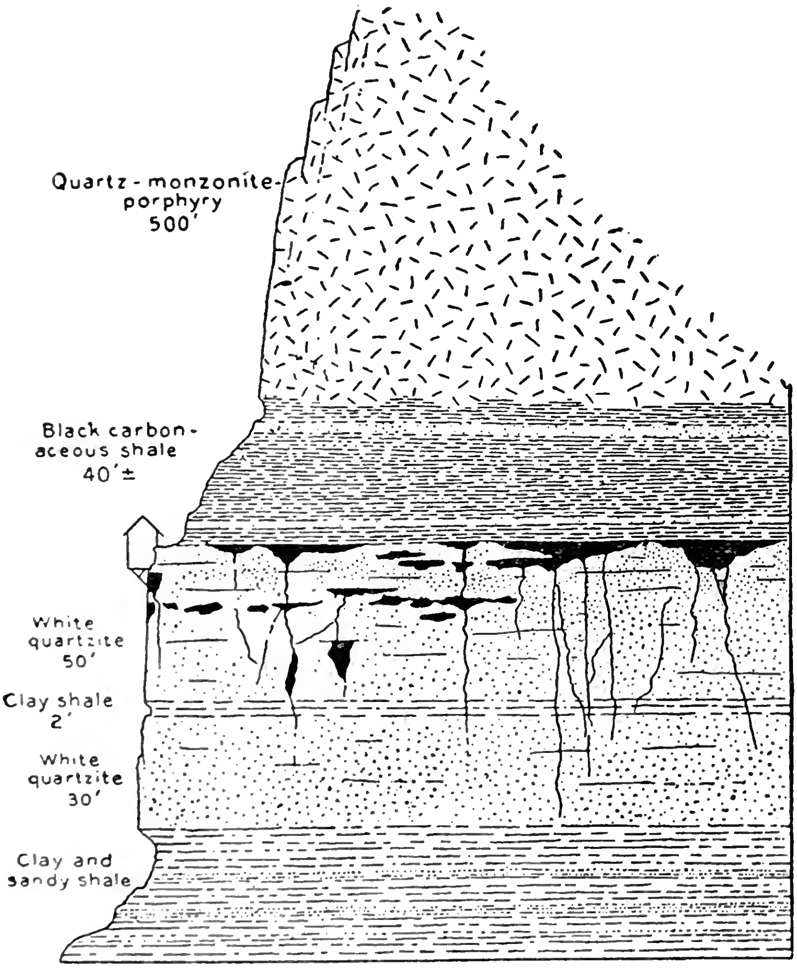


FIG. 16.—Cross-section of the American Nettie Mine, showing how pear-shaped shoots of ore have formed beneath imprevious barriers of shale. (After U. S. Geol. Sur. Bull. 260.)

In the case of the Tornado Mogul shoot, the largest body of refractory siliceous ore in the Black Hills region, the ore body is bounded on one side by a dyke of phonolite which has served to assist in the general stagnation of the solutions and has resulted in the production of a very large body of ore. The same stagnation has been produced in the Elkhorn mine in Montana, as described by Weed, where solutions have risen and produced bodies of ore under anticlinal domes of impervious rock.[1]

[1] Weed, U. S. Geol. Survey Twenty-second Ann. Report, pp. 22 to 92.

FIG. 17.—The drifts follow the lines of fissure as shown in the section in Fig. 16. The mine workings thus bring out clearly the fissure systems.

It is to be remembered that in all cases where fissures or openings transect different types of rock the ore will (unless the mass of replaceable rock is very small) have some *free face* from which the nature of the process may be inferred, and which will show the usual sharp, wavy contour or gradual transition to rock that is characteristic of replacement ore deposits.

Stagnation of solutions and consequent increase in the lateral extent of an ore body need not, of course, be determined by an impervious barrier. The constriction of openings which decrease the rapidity of flow can occur within a single homogeneous rock mass and will cause the solutions to spread laterally and produce the wandering forms which are shown in many of the Leadville ore bodies.

This will also account for the occurrence of not a few bodies of ore wholly enclosed in limestone in the Leadville district. Most of the ores occur *directly beneath* the impervious capping; but some of them occur wholly within the limestone, and in these cases it is presumable that the solutions never reached the impervious barrier.

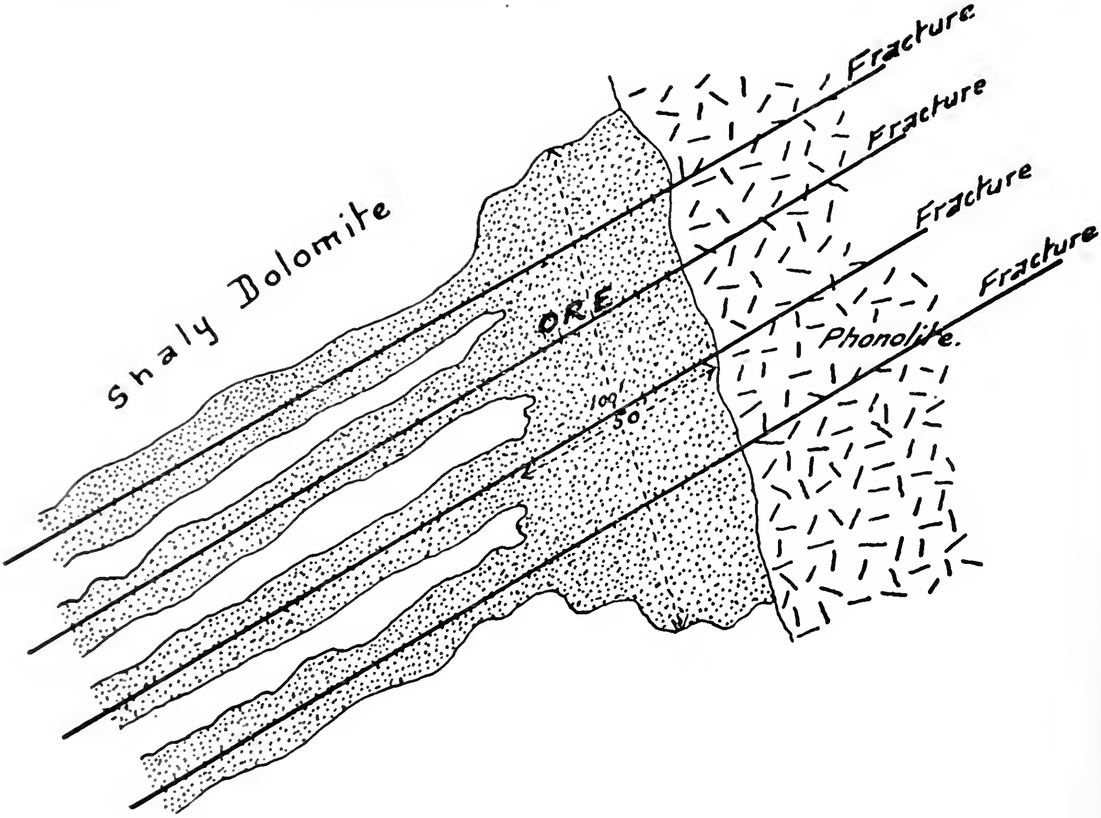


FIG. 18.—Sketch plan of the mineral farm ore-body near Portland, South Dakota, showing how replacement of the country rock by silica has proceeded outward from the fractures, but has only completely replaced the intervening rock when the porphyry barrier has dammed up the mineralizing waters.

EFFECT OF MANNER OF OPERATION OF SOLUTIONS ON ROCK.

If the replacement starts from a fissure in a homogeneous rock mass it may be conceived to operate in one of two ways.

(1) The solutions may have first penetrated the rock along minute pores until they have saturated it for some distance from the fissure, the limit being set by the balance between the friction of diffusion and the difficulty of escape elsewhere, and the solution may then operate from an innumerable number of separate centres (those farther away being fewer in number). As these separate small masses grow, they gradually interfere until coalescence unites them into one continuous body. At the edges of of the body the centres of growth are more widely separated and the resulting masses are disunited so that one may pass

outward through first a solid mass of ore, then through thickly disseminated particles of ore, then sparsely disseminated particles, and finally into country rock entirely beyond the zone of alteration. It is obvious that this process of replacement may be arrested at any stage, either through lack of further supply of solution or through the final neutralization of all the chemically active agents in the circulating waters. If the process is arrested early the replacement will be incomplete, and will have the form of a mineralized zone throughout which little particles (often perfectly formed crystals) are abundantly scattered but nowhere united into an integral mass. Such replacement is that described by Lindgren from specimens of silicified limestone from Aspen. See Figs. 19 and 20 above. Replacement as seen in Fig. 19 has started at a number of separate centres. Then later the perfect crystals so formed have been surrounded by more replacement quartz until the whole mass is replaced as in Fig. 20. The hexagonal outlines of the earlier formed crystals are still to be seen in the ore and have been, so to speak, the advance agents of the process.

Pyrite cubes embedded in later pyrite are common in Leadville ores and illustrate the same feature.

(2). The second manner of operation is quite different and is typically illustrated by the Black Hills siliceous gold ores Here, again, taking a single fissure or channel of access as the easiest method of illustration, the boundaries of the ore are abrupt and all rock from the fissure to the final limit of mineralization is completely replaced. In all of the great multitude of ore bodies which the writer has studied in this region, in no single case was a gradual transition from ore to rock observed. The boundary is often so sharp that no scale is so small that one division of it will not rest on ore and one on country rock. Even in the smallest masses the abrupt transition is observable.

In cases of this kind the rock adjacent to the fissure must first have been replaced, then that farther away and so on until when the process was arrested the boundary was left sharp, however far the alteration may have proceeded. In other words, the replacement has advanced like a wave over the country rock until its termination has arrested it at some point. If the process has operated in this way the advancing solutions must have found their way constantly through the newly formed ore and as this is generally quite porous, due to the innumerable little cavities left by the decrease in volume, it has probably gained access to the outer wall in this way. This seems to be further proved as these volume vuggs often contain crustified linings of minerals which have been deposited from the ore solutions, such as quartz and fluorite.

When replacement proceeds in this way no disseminated ore is produced.

Whichever of these two ways has been the manner of operation the process has involved two distinct results, the introduction of the new mineral and the removal of the old. The latter might be termed the disposal of refuse. The dissolved rock has needed to find its way out just as the old has needed to find its way in.

It is not difficult to see how this could have occurred, because it is evident that the high temperature and dilution of ore-bearing solutions must have been accompanied by a division into ions which can have travelled back and forth through the solutions during the process, the ions of dissolved material moving back along the same paths as those of new material which were proceeding in the opposite direction.

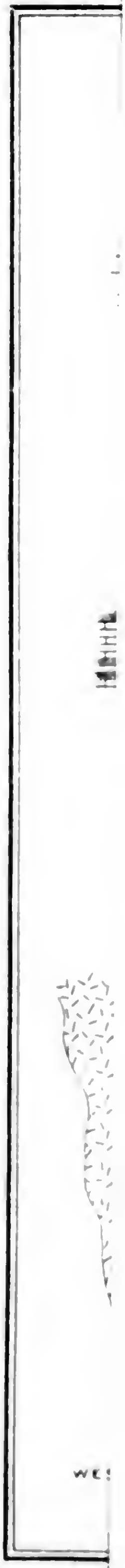
In some cases, when the solutions have been apparently saturated with dissolved rock at the close of the process, the original rock substance has been again precipitated in the volume cavities, filling in the spaces of the vuggs between the minute crustified linings which occur in them. Such minerals might well be termed *renascent minerals*, to distinguish them from the *juvenile* minerals deposited from the original solutions.

It is aside from the purpose of this paper to enter further into the questions of physical chemistry involved in the process, for they are difficult and complex and only to be inferred from geological evidence; but these suggestions may serve to stimulate experimental work along these lines.

THE AMOUNT OF MATERIAL SUPPLIED IN SOLUTION.

If the supply of mineralizing water is great and its introduction extends over a long period of time, the replacement will, of course, extend much farther from the channel of access than

PLATE I



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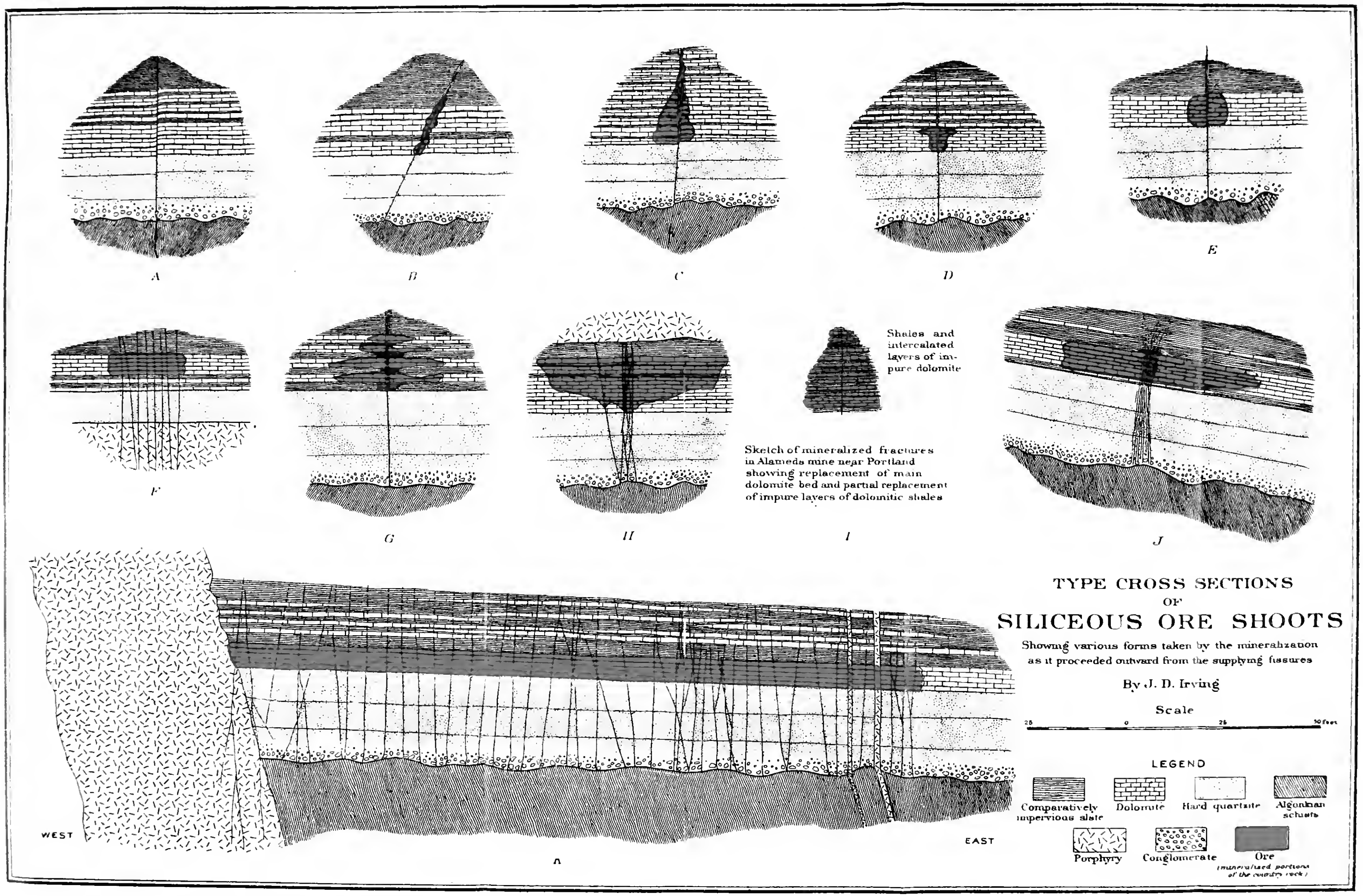

(After Irving, Prof. paper 26, U.S. Geological Survey).

if it is very slight. This is well illustrated in the (Plate II) comparative series of cross sections of ore shoots in the Black Hills.

Ore shoots frequently terminate along their strike, although the fracture or opening may continue, and is sometimes as large as that where the ore-body is extensive. The supply of solution seems to have been confined chiefly to certain areas and its amount has been insufficient to produce extensive replacement except in the heart of the channels of flow. Cross sections I, J, K, L and M, Plate II, show progressively decreasing amounts of mineralization from single verticals.

When all of the causes which influence the form of a replacement mass are together present in a single ore-body—viz., form and distribution of channels of access, varying porosity, varying susceptibility and varying supply of mine waters, it is often difficult to determine what cause has exerted the maximum effect; but it rarely happens that some portion of an ore-body cannot be found where each has alone been the determining factor.

III.—ROCKS AFFECTED BY REPLACEMENT.

Although this paper does not aim at a discussion of the chemical side of replacement processes, a few words as to the susceptibility of the main rock groups are necessary.

It has been clearly shown by previous writers, notably Lindgren that replacement may occur not only in calcite, dolomite, and other readily soluble minerals, but in a great variety of other more insoluble minerals, a few only escaping, even quartz suffering often times at the hands of calcite, siderite and minerals ordinarily considered quite soluble. It therefore follows that rocks made up of aggregates of these minerals will suffer replacement.

As different minerals are differently affected by solutions, rocks will be more or less completely replaced according as they are made up of aggregates of the same or of different minerals. Pure or fairly pure limestones being composed of aggregates of calcite or dolomite grains with comparatively little other material, and that scattered widely through the rock, are far more extensively and completely replaced than any other type of rock. The disseminated types of replacement bodies in them are therefore relatively rare. As alumina and silica increase, they are the receptacles for less and less pure ore masses, the alumina and silica often persisting unaltered in the ore resulting from replacement. Shale bands, rounded detrital quartz grains, etc., therefore remain unaffected and often constitute valuable criteria for the recognition of the process. Sandstones and quartzites are far less *extensively* affected, though they are perhaps as often replaced as limestone. Deposits in them, owing to their greater porosity, are apt to be disseminated and incomplete, starting as they do from innumerable centers at the same time and proceeding only slowly and with difficulty in so resistant a mineral. In the calcareous sandstones where the cement is calcite, the calcite is often replaced and the detrital grains of quartz left unaltered. In such replacements it is frequently a matter of extreme difficulty to distinguish between impregnations or the filling of intergranular spaces, and the actual replacement of the component grains of the original rock.

The least easily attacked rocks among the sediments are those containing high percentages of alumina. Such are the clay shales (and their metamorphic derivatives). Those containing these high percentages of alumina suffer least and will often persist without alteration in replaced limestones. Shales with high percentages of lime are often very extensively replaced.

With the igneous rocks, which are essentially heterogeneous, the conditions are usually different. They are aggregates of different minerals which are very differently affected by any given solution. For this reason igneous rocks are rarely wholly replaced, and deposits formed in them are generally disseminated or scattered, that is, solutions have exercised a selective effect, replacing some minerals and leaving others untouched or affecting them in a different way. Furthermore, the pore space for the access of solutions is extremely small, as will be shown later. Instances of this type of replacement are Ely, Nevada, the porphyry coppers of Bingham, Utah., and other similar occurrences.

FIG. 21. Quartzite partly replaced by siderite and pyrite Helena and Frisco mine, Cœur d'Alene, Idaho. Q=quartz grains; S=Sericite; Si=Siderite with partly rhombohedral form; black=pyrite. Magnified 100 diameters. (After Lindgren, T.A.I.M.E., Vol. XXX, p. 635.) Shows how crystal faces intersect original grains and metamorphic structures.

FIG. 22.—Incipient Tourmalinization of Quartz. Three quartz grains shown. Needles single and in bunches of tourmaline. Mount Bischoff Tasmania. (Alfred W. von Fircks, copied by Lindgren in T.A.I.M.E. Vol XXX, page 637.) Shows how crystals of tourmaline pass from one quartz into the other.

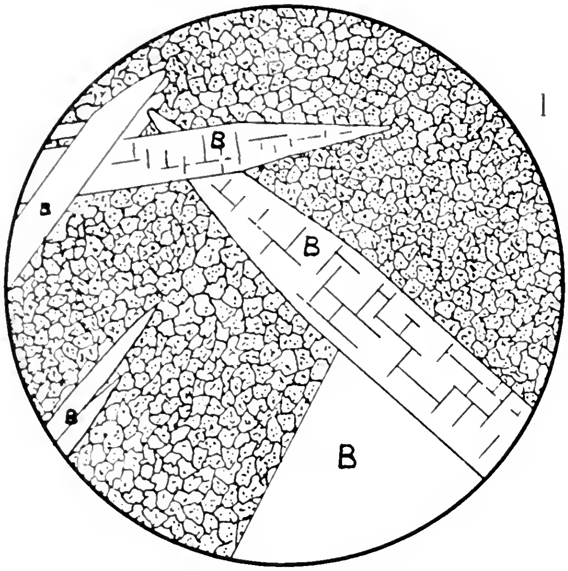

FIG. 23.—B=Barite. 1=Gray, fine-grained limestone.

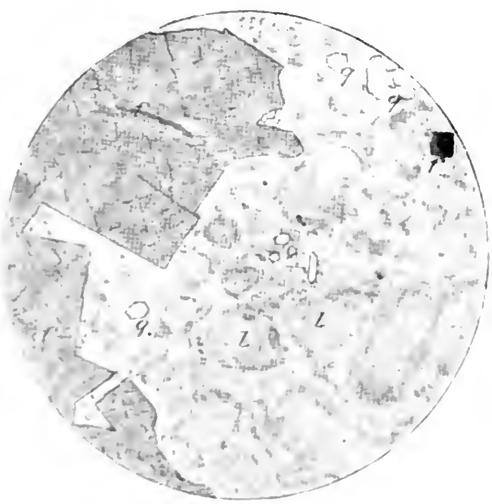

FIG. 24.—(After Lindgren). Fluorite replacing limestone. Florence Mine, Judith Mountains, Montana. *f*=fluorite; *l*=limestone; *q*=secondary quartz. Note how crystal boundaries are perfectly developed on fluorite and quartz crystals.

IV.—THE CRITERIA OF REPLACEMENT.

GENERAL.

The recognition of an ore-body as the result of replacement may be carried out by many different criteria. It rarely happens that all of these criteria may be applied to a single deposit, but in most cases one or more of them will be available. Many of them may be applied directly in the field, others require the use of the microscope.

That the discussion which follows may be more easily understood the appended classification of criteria is given:—

1. Presence of complete Crystals in foreign Rock masses.
2. Preservation of Rock Structures.
3. Intersection of Rock Structures.
4. Absence of Concave Structures.
5. Absence of Crustification.
6. Presence of Unsupported Nuclei.
7. Form.
8. Decrease in volume due to changes in composition.
9. Excess of volume of introduced mineral over original pore space of rock.

It is important to understand that the Criteria which are most serviceable in recognizing replacement may most of them be eliminated by regional metamorphism. Any class of ore-deposit may suffer metamorphism, together with the enclosing rocks. Original structures are then completely obliterated. If such metamorphism is extreme, ore-deposits afford no criteria as to the part played by replacement in their original formation.

1. COMPLETE CRYSTALS IN COUNTRY ROCK.

At the edges of those replacement masses in which the transition from ore to rock is gradual, or in cases where the new mineral is sparsely disseminated through the country rock in the vicinity of some minute crevice or cavity, an examination by the microscope will often show that the new mineral has complete crystalline form, that is, has all of its faces developed.

Crystals which grow in cavities are attached to the walls of the openings in which they are deposited or to other earlier deposited crystals and therefore never have all of their faces completely developed. Even where not perfectly developed, the relations of some one crystal face to the grains of the original rock affords an excellent criterion. Crystals of this kind may occur in sedimentary, igneous or metamorphic rocks and their value as indications of replacement is in each case determined by different criteria.

Complete Crystals in Sedimentary Rock.

Sandstones and quartzites consist of more or less water worn grains of quartz deposited in the form of solid particles. In quartzites the grains are cemented by later added silica, but can usually be distinguished from it. Complete crystals of pyrite, fluorite, galena, siderite, tourmaline, and other minerals, often occur in such rocks showing perfectly or partly bounded crystals embedded partly in one grain and partly in another, as the crystal faces extend through and intersect two or more grains of the original quartz. Fig. 21 (after Lindgren) shows quartzite partly replaced by siderite and pyrite, and Fig. 22 (also after Lindgren) shows needles of tourmaline transecting the clastic grains of quartz which they replace, or entirely within them. Many other illustrations might be given.

It is evident that these crystals could not have been deposited with the sand grains of the original rock, first because they are often too soft or friable to stand attrition without being destroyed, or at least marred during deposition, and second because the solid particles of quartz could not afterward have been moulded around them. Nor could they have started their growth in the interstices between the quartz grains and forced the grains apart by virtue of the force of crystalline growth, for that would not have resulted in the carving out of the perfectly fitting cavities in which they are found. Microscopic examination on many such specimens also shows that in no case except that of rocks already metamorphosed do the constituent grains of the original rock show any strain phenomena such as wavy extinction or any other optical evidence of strain. The only other possible explanation of their presence, aside from replacement, is that cavities have first been dissolved by circulating waters of exactly the shape and size of the crystals to be later deposited—a view which ascribes to circulating waters a sentient power, which is manifestly absurd.

If they be formed by replacement, however, no such difficulties arise. Solutions containing the ingredients of the new minerals dissolve the old and substitute the new in its place, molecule by molecule so that no discrepancy between space and crystal grain can occur which is larger than the diameter of a single molecule. It is possible that the force exerted by the crystalline growth of the new mineral has increased the pressure around its periphery to such an extent as to materially aid in the solution of the old mineral and the simultaneous substitution of the new.

Aside from their relation to individual grains crystals of this kind may also intersect the sedimentary bands of the original rock or other minute and easily recognizable original structures, such as fossils, cross bedding layers, etc., showing that they have been introduced subseqeunt to the formation of these structures.

In limestones such well developed crystals or groups of crystals are even more frequent. Fig. 23 shows large crystals of barite developed in a fine grained granular limestone. Fig. 24 (after Lindgren) shows crystals and clusters of crystals developed by replacement in limestone.

In shales the case is somewhat different. Here the component particles of the original rock are extremely fine and likewise the banding. Newly introduced crystals can grow in such rocks by forcing aside the shaly material and compressing it to one side or the other. Fig. 25 shows a drawing taken from Chamberlin in which the crystals of blende may be seen with the banding of the shales passing up around them.

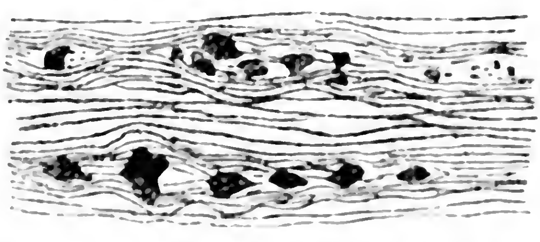

FIG. 25.—Section of a portion of "Speckle Jack," showing the manner in which crystals of blende are imbedded in the rock and the curvature of the laminæ about them. (After Chamberlain: Geology of Wisconsin, Vol. IV, p. 474.)

Fig. 26, however, shows a specimen of ore in which the galena fairly transects the original shale bands of the rock and is evidently a replacement. This is taken from a drawing made by the writer from a specimen from the Federal Lead Co.'s mines in Missouri.

FIG. 26.—Cube of galena, G, replacing limestone. The crystal squarely intersects the shaley layers. Drawn by the writer from specimen from mines of Federal Lead Co., Mo.

It is therefore important in dealing with shales to determine if the crystals have grown by a distortion of the original layers of rock material or by actual replacement.

Metamorphic rocks.—In metamorphic rocks the same feature may often be observed. In certain specimens of ore from the Homestake mine crystals of arsenopyrite have developed in the schist and the schistose structures pass up around them just as in the case of shales, forming peculiar knots in the rock when it is split without actually disclosing the kernel of ore beneath.

In general in metamorphic rocks the same criteria may be observed but in addition it is important to determine if the newly introduced crystals (1), intersect the metamorphic minerals such as garnet, staurolite, etc. (2), if they intersect and are hence later than metamorphic structures such as schistosity, etc. and (3), if they themselves are entirely free from shattering or strain due to metamorphism. If these three factors are determined it is safe to say that they have been introduced after metamorphism and their intersection of typical metomorphic minerals may then be taken as positive evidence of replacement.

In regard to the evidence of crystals such as those just described it will be interesting to quote Mr. Lingren's statement[1]:

"The only decisive criterion (of molecular replacement) is that of metasomatic pseudomorphism involving the proof (generally furnished by microscopic study) as to whether simultaneous dissolution and deposition have actually taken place. The most satisfactory proof is the distinct alteration of well defined crystals (or at least well defined grains) of the original mineral into the secondary mineral in such a way that the latter projects into former in prisms and fibres having crystalline outlines. Another proof is afforded by sharply defined crystals of the secondary embedded in the primary mineral

[1] T.A.I.M.E. Vol. XXX, pp. 595-596.

without any break between their surfaces; but in this case it must be clear that the replacing mineral is really secondary and was not formed before the primary. Another satisfactory proof is given, if for instance, in a sandstone the newly formed mineral has in part a crystalline form and its surfaces squarely intersect the grains of clastic material which it partly replaces "

Igneous rocks.—Complete or partially developed crystals in igneous rocks can be attributed with certainty to replacement only when there is no doubt as to their secondary nature. The constituent minerals of such rocks have crystallized from molten magmas and those which have crystallized first will often show well developed crystalline forms, the other minerals moulding themselves about the faces of the earlier formed crystals. Quartz for instance frequently occurs in doubly terminated pyramids in rhyolite porphyries in such a manner that all of its faces are perfectly developed, but as it is one of the ordinary original constituents of the rock no confusion can arise as to its primary origin.

With these rocks only such minerals as cannot occur under gneous conditions can, from the crystalline form of the mineral alone, or from its relation to the adjoining grains of the rock, be ascribed to replacement. When such minerals as siderite, calcite, arsenopyrite, and other minerals not characteristic of igneous rocks occur in them with faces which intersect or interpenetrate the other minerals of the rock, little doubt exists as to their secondary nature. With the other more usual minerals of ore-deposits such as galena, pyrite, sphalerite, chalcopyrite, pyrrhotite, the case is more difficult for while the occurrence of such minerals as original crystallizations from magmas is rare, many petrographers believe that the metallic sulphides form in igneous rocks as primary minerals and their intergrowth into adjoining mineral grains cannot therefore be used with certainty.

Assistance is furnished by the relation of mineral grains of the supposed new mineral to channels of access in the rocks. If pyrite for instance is thickly disseminated in crystals or partially faceted grains through the rock in the neighbourhood of a crack or other opening and then gradually dies out as distance from the conduit is gained until in the normal rock it is absent, its crystalline form and the transection of the other constituent grains by one of its crystal faces may with certainty be used as an indication of its formation by replacement. Its relation to the fissure is enough to establish the fact that it is not an original igneous mineral.

Its relation to the other grains will then determine whether it is a cavity filling or a replacement. Assistance is also furnished by the character of the mineral grains which it intersects. Thus a pyrite crystal which cuts into one of the faces of a perfectly developed quartz phenocryst is probably formed by replacement as the phenocryst would have been an early crystallization in the magma and would probably not have included a pyrite crystal partly in the mass but would have thrust it aside into the still molten mass or else have included it entirely so that it could not be forced out during crystallization.

The association of metallic minerals with other products of thermal alteration such as sericite while absent in all fresh and unaltered rock will also serve to render this criterion of value.

2. PRESERVATION OF ROCK STRUCTURES.

All rocks are characterized by certain structural or textural features which are either peculiar to them or have been later induced in them by the action of pressure or dislocation. Original structures, such as stratification, cross-bedding, fossils or fossil groups, are characteristic of sedimentary rocks, phenocrysts of igneous rocks and schistose and gneissoid structures of metamorphic rocks. Such structures are rarely to be confused with any of the structures met with in epigenetic ore masses.

Later disturbance may induce secondary structures, such as folds, brecciated structures, joints, minute faults, etc., which may extend through considerable areas of a rock mass.

Original rock structures are often preserved in ore masses and these serve as an excellent indication of replacement. There is probably no criterion which may be quite so readily detected nor any which is so generally serviceable.

In order that a structure may serve as a definite criterion for replacement it must either be such as is definitely characteristic of the original rock or a later induced structure that can be shown to have existed prior to ore-deposition. If a structure can be independently formed in an ore-mass which fills a cavity it will be of less certain value as a criterion. There is usually no difficulty in making the distinction for original rock structures as these are generally very characteristic and are not often easily confused with ore structures. With later induced structures such as folds, faults, joints, etc., it is not so simple, as the ore itself may suffer like deformation. In such cases the intersection of the secondary structures by the ore mass in such a way that the structure is partly in the ore and partly in the rock will often be of assistance. (For this criterion see following pages of this paper.)

The original structural features of rock masses which may be retained in ore are of all sizes from those which are large enough to be readily seen in the field to those which are so minute that they need the microscope for their indentification. It is in general true that the retention of larger rock structures in the ore are more readily serviceable for the detection of replacement and that the more minutes structures approach more nearly a positive proof of the molecular nature of the process. No retention of rock structure however minute can serve to distinguish absolutely between molecular replacement and the solution of very small spaces and later mechanical deposition in them. The microscope does not afford a means of detecting structures which approach the actual sizes of molecules. We can therefore only use this criterion as a strong indication of the process and must rely on the complete crystals mentioned on page 427 et seq. for a proof of its ultimate molecular nature.

From the evidence afforded by such crystals, when they occur as outliers of ore masses which show other criteria, the molecular nature of the process may be inferred for the entire mass, and the preservation of structures in the ore mass as a whole may often be carried down to such small microscopic features that, while not amounting to absolute proof, little doubt is left that the interchange of material is of a molecular character.

The rock structures that may be preserved in ore-masses may be conveniently grouped as follows:—

Original Rock Structures	1. Stratification 2. Cross-bedding 3. Fossils 4. Dolomitization Rhombs	Preserved in Ore Masses replacing sedimentary rocks.
	5. Phenocrystals	Preserved in ore masses replacing igneous rocks.
Induced Rock Structures	6. Joints and Faults 7. Brecciated Structures 8. Folded Structures	Preserved in Ore Masses replacing any rock.

It is apparent from this table that the structures characteristic of metamorphic rocks such as schistosity, gneissoid structure, etc., are not mentioned. They are omitted because, like other features such as vesicular structures in lavas and some others, they have not yet been detected in any ore mass so far studied in relation to replacement. This is in part due to the resistent nature of the rocks in which such structures occur and the different chemical character of the component minerals. Replacement of such rocks is often incomplete and results in disseminated grains of mineral scattered through the rock which are too far separated to show any preservation of original structure. It is probable, however, that further study will much increase the number of such preserved structures and well-defined schistose or gneissoid structure would then afford a valuable criterion.

Character of the Ore in which Structures are Preserved.

The preservation of structures is more perfectly carried out in some classes of ore than in others. Silica preserves them more perfectly than other minerals and often occurs in such minute grains that only with the microscope is it possible to discover the individual grains of the replacing mineral. An interesting instance is the preservation of the minute structure of the wood in the case of silicified trees. With the sulphides the preservation of structures is not so easy to detect, on account of the opaque nature of the mineral and the tendency of the component grains to grow by interpenetration into the grains of the original rock and the consequent obliteration of all of the more minute structural features. In some cases, however, fossil shells preserved in pyrite have been noted and stratification planes are often so preserved, though usually less perfectly than in ores largely composed of secondary silica. It is not always easy to determine just what causes the retention of the form of the original structure. In the case of limestones replaced by silica it is partly due to the arrangement of the quartz grains in aggregates of different sizes (see Plate IV), and partly through the inclusion in the replacing quartz grains of the original organic impurities of the limestone. The foraminiferal test in the upper of the two cuts in Plate IV. shows this; that is, the quartz which has replaced the rock has not disturbed the arrangement of the original particles of foreign material of the rock but has replaced the calcite about them and

Plate III. —Face of ore in the No. 2 shoot, Union Mine, near Terry, Black Hills, South Dakota. The original rock is thin-bedded shaly limestone; the ore is silica with small amounts of pyrite and fluorite, gold values about $20. The stratification is here shown preserved in the ore body, although the limestone has been entirely altered to ore. (After U. S. G. S. Prof. paper 26, Plate XVI.) The scale is shown by the shovel handle.

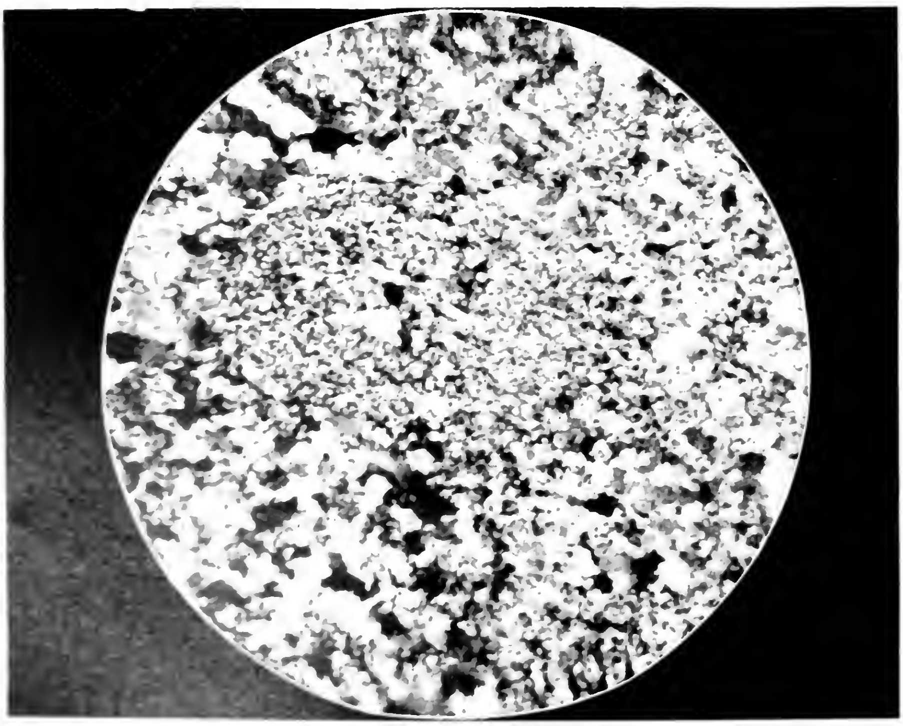

Plate IV. Thin section of silicified limestone, showing outline of [illegible]. Upper section is with ordinary light, lower with polarized light. [illegible]

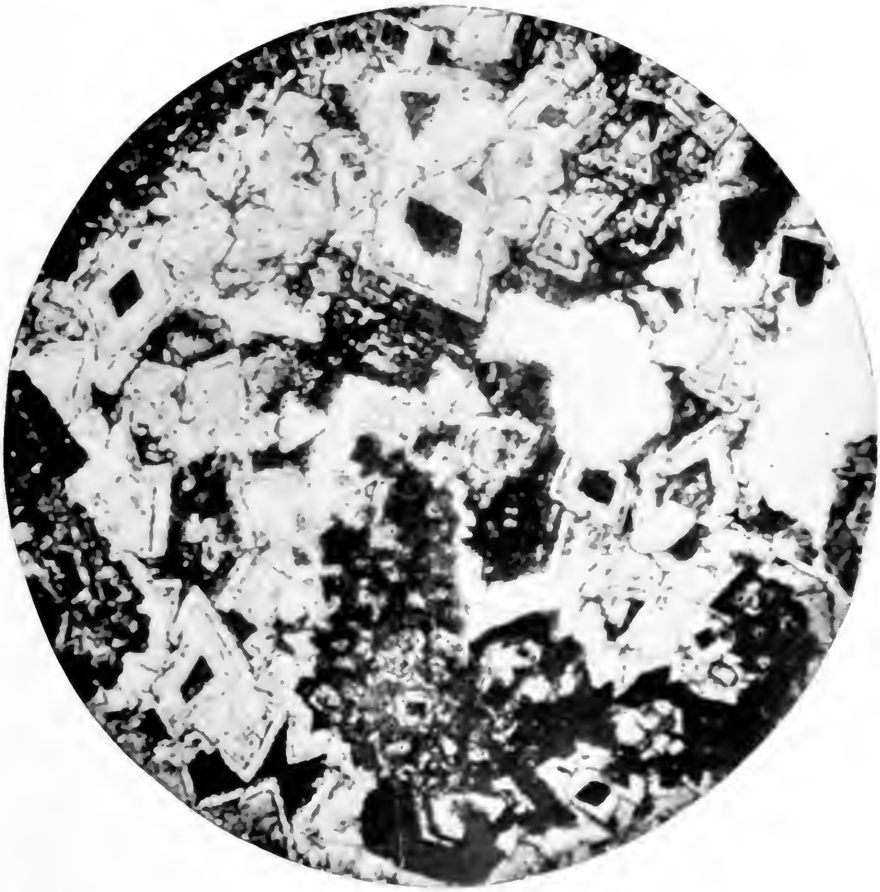

PLATE V.—Shaly dolomite, showing rhombic crystals of dolomite which constitute the rock and are shown preserved in siliceous ore in Plate VI. A higher power objective is used in this cut than in Plate VI, so that the rhombs look larger in this figure.

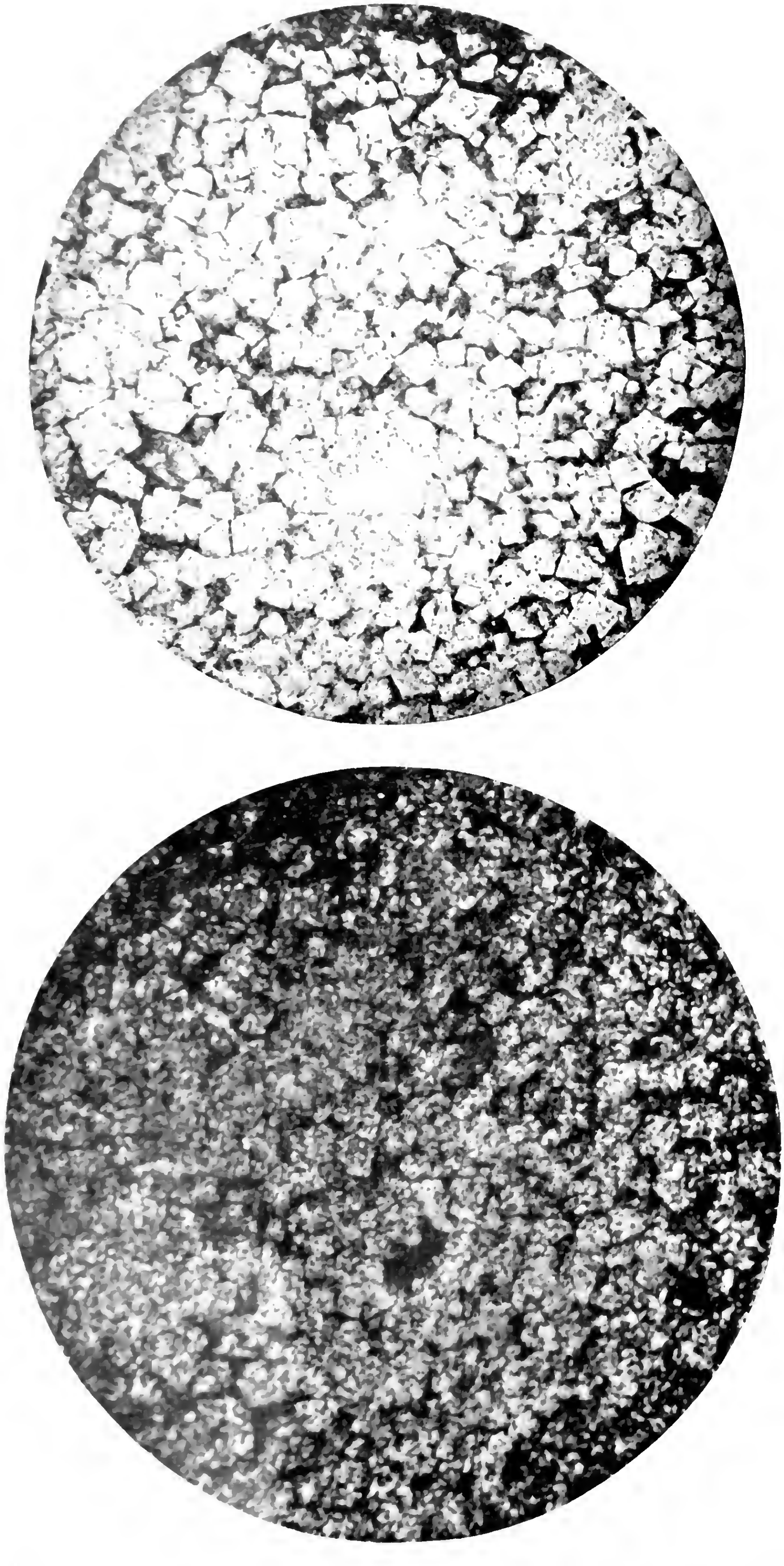

PLATE VI.—Rhombic structure perserved in siliceous ore, due to replacement of carbonate as shown in Plate IV. Upper cut="A," lower cut="B."

left them in their original position. In consequence an examination of siliceous ore without the polarizer will show the original outline of a foraminiferal test or dolomite rhomb as determined by minute unreplaceable particles of foreign matter, but the application of the polarizer shows that the place of the lime has been entirely taken by silica.

Original Rock Structures.

Stratification.—All unaltered sedimentary rocks are characterized by a division into layers or strata, which may vary in thickness from the thinness of paper to a hundred feet or more.

When the beds are of great thickness no preservation of them in the ore mass is usually noticeable as the ore bodies are then often of less size than the individual beds or layers. When the layers are thin they are found frequently preserved in ore masses.

As ore bodies which fill open cavities are often banded it is important not to confuse preserved stratification with banded structure. In most cases the distinction is not difficult. Preserved stratification is always conformable or continuous with that of the enclosing rock while banding, due to ore deposition, is often at variance with the stratification of the surrounding rock. Silification, for instance, of shaly limestone occurs in the Cambrian sediments of the Black Hills of South Dakota. The sediments are intersected by minute fissures and large masses of ore have been formed by the replacement of this limestone chiefly by silica and a little pyrite. The banding of the original rock extends continously into and through the ore and again into the country rock on the other side although the substance of the rock is entirely altered to ore. In some cases this banding is so perfectly preserved that it is impossible to distinguish between country rock and ore except by a slight difference in colour and the hard brittle nature of the material. Fig. 10 page 413 shows a sketch of a small off-shoot in the Dividend Mine, near Portland, South Dakota, in which this continuity of banding is admirably illustrated:—

Plate III, is a photograph of an ore face in the Union Mine near Terry, South Dakota, showing the preservation of banding in the ore. The boundary between the ore and the adjoining rock is usually very sharp and the strata pass uninterruptedly across the line of demarcation, being composed on one side entirely of carbonates and on the other entirely of silica and pyrite. As is usual in replacements where the mineral introduced is chiefly silica the structure is more perfectly preserved than in the case of solid masses of metallic sulphides. The regularity is somewhat disturbed by a slight decrease in volume as the ore has less volume than the rock replaced and the ore is thus characterized by a large number of irregular vuggs or cavities which are not present in the original rock. The bedding planes are even more regular than indicated by the photograph as the broken face is irregular and the fore-shortening produced by the perspective of the photograph has produced a wavy appearance that does not actually exist in this ore-face. An examination also of Fig. 15, page 418, and the comparative series of cross-sections, (Plate II) will give an even better idea of the manner in which the bedded structure passes continuously through the ore.

On the other hand banding due to crustification or the deposition of ore in layers is usually independent of the rock structure. In some cases it will form a lining to the entire open space as shown in the lead and zinc ores of the Iowa-Wisconsin district. Fig. 27, shows this feature.

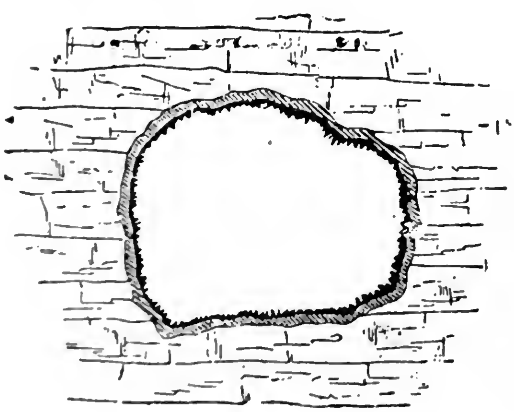

FIG. 27.—(After Chamberlain: *Geology of Wis.* Vol. IV, p. 467). Cavity formed by solution and afterwards coated with a crustified lining of pyrite next the rock and blende attached. The banding of the sulphides is independent of the rock structure.

Smith and Tower cite an instance from the Tintic district in Utah where the banding of the ore was discontinuous and unconformable with that of the enclosing limestone:

"In the Eureka Hill Mine, 300 foot level, a large cave deposit was found, consisting of alternating bands of quartz and cerussite. These bands are horizontal and at right angles to the stratification of the limestone."[1]

In such cases as these little difficulty will be experienced in making the distinction between preserved bedding and ore-banding, nor has the writer ever observed any instance in which the distinction offered any difficulty. It is conceivable, however, that in veins formed by the filling of spaces of separation between rock strata where crustification is parallel with the bedding of the enclosing rock confusion might arise and in such cases some other criterion will need to be sought.

In using this preserved stratification as a criterion it is important to distinguish between preserved bedding planes and residual bedding planes. The laminæ of sediments may be formed either by a difference in the size of the grains composing them or by a difference in the chemical composition of the material. In the illustration given the rock is composed entirely of layers of carbonate of lime and magnesia with very small quantities of clayey material. The entire rock has therefore been replaced and the bedding planes in the ore are a preserved structure. In many instances (very common in the Black Hills silicious ore districts) the rock is made up of alternate laminæ of clay shale and carbonate of lime and magnesia. The lime has in these cases often been extensively replaced, but the resistant nature of the shales has caused them to remain unaffected in the ore. Such persistent layers are most properly termed *residual structures*. Their significance as an indication of replacement is discussed under the heading of Unsupported Structures. (See page 460.)

In addition to the Black Hills of South Dakota, the retention of sedimentary banding in ore masses has been observed in a number of other places of which Leadville, Colorado, and Bingham, Utah, are interesting examples.

Leadville. The sulphide masses of Leadville are composed of pyrite, sphalerite and some galena; chalcopyrite is in very small amount in the unenriched primary ores. When these ore masses are enclosed in beds of pure limestone which is uninterrupted by

[1] Tower and Smith. Geol. and Min. Ind. of the Tintic district, Utah, XIX Am. Rep. Pt. III, Plate LXXXIV, U.S.G.S

any bands of more resistent and unreplaceable shales the entire mass of the rock has often been replaced and it frequently happens that there is in a freshly broken face of ore no evidence of banding. If, however, the face has stood exposed for some months so that layers of dust have accumulated on it, the dust adheres to the sulphide which has replaced one layer in a slightly different manner from that which has replaced the next adjoining layer. This is probably due to a slightly different arrangement of mineral grains in the ore produced by the varying susceptibility of the different layers to replacement and serves to preserve in a faint, but suggestive manner the original banding of the sediments. Mr. S. F. Emmons[1] in discussing the origin of these sulphide masses says:—

"In the great bodies of the A. Y., Minnie, and adjoining mines, not only could every detail of the granular structure, joints and cleavage of the original limestone be detected at times in the sulphide ore, but even the cracks in the top. In abandoned drifts where limestone dust had accumulated on the walls, one would have supposed the walls to be all limestone until the breaking off of a fresh fragment by the hammer showed the metallic gleam beneath."

In Tintic, Utah, Tower and Smith describe the ore bodies of some of the mines as showing the structural features of the limestone but the bedding of the stratified rocks is not represented as being preserved.

Bingham, Utah. The large copper shoots which occur in limestone at Bingham, Utah, and which are shown in plan in Fig. 28, show a remarkable preservation of the stratification of the country rock. As is usual in sulphide ores this banding is less easily observed and less perfect than in replacement by silica; but its continuity with the bands in the adjoining rock is striking. These ore bodies are thus described by Boutwell:[2]

"As we stated in the description of the structure of the copper chutes (p. 155), the broad characteristic of this structure is banding. This banding is not like the crustified or even the roughly banded structure of the lodes, but is a bedding which in form is identical with the bedding of strata. The chief difference is in composition, these beds being composed of ore instead of limestone or quartzite. Bedded structure characterizes alike miniature ore bodies, mineralized wall rock adjacent to seams, and large lenticular ore shoots. Thus mineralization adjacent to fissures in limestone took place

[1] S. F. Emmons, T.A.I.M.E., Vol. XXIII, p. 602.
[2] Boutwell. U. S. G, S., Prof. paper No 38, p, 193.

FIG. 28.—Plan of Ore-shoots in Jordan and "Highland" limestones, Old Jordan Mine, Bingham, Utah. (After Boutwell, U.S.G.S. Prof. paper 38, Plate XL.) These ore bodies show the preservation of the stratification of the enclosing rock in the ore. (On the original plate the stopes are represented in out line and the mine workings are shown. The writer has constructed this plate by filling in the stopes and omitting the workings.)

along beds. Further, the marked deposition of ore along certain beds, and the slight deposition along others, appear to indicate a selective tendency on the part of mineral in solution for more soluble beds. Similarly, in small shoots the massive structure is a bedding of massive ore, which is more extensive in some beds than in others. Finally, the immense lenses of cupriferous pyrite, e.g., those in the Highland Boy, exhibit the same massive bedded structure. This selective action leads to a very irregular periphery. The transition from massive, solid ore to barren country on the periphery is not sharp, as in the case of the lodes, where the transition from the rich bands to barren wall rock is well defined. On the contrary, it is gradual, passing from the bed of rich copper sulphide through lean copper ore, still poorer ore, merely stained country, to normal, barren, marble country. Although the composition changes from ore to barren country rock, the structure is persistent, to that a bed of ore is clearly seen to be a portion of the same bed of country rock; in other words, the ore has retained the bedded structure of its country rock. . . . .

"The foregoing general examination of the copper ore in limestone indicates that the copper shoots in limestone have a bedded structure, and that the bedding corresponds to the stratification of the country. These features are generally considered to signify in a broad way that the ore has taken the place of the country rock by substitution. They are characteristic of "replacement" deposits, and accordingly suggest that the copper deposits in limestones were formed by replacement."

Cross-bedding.—So far as the writer has observed or been able to discover in the literature, no cross-bedded structures are known to have been preserved in the ore of replacement ore-bodies; but there is little doubt that such structures will be found if a careful search is made for them in ore masses which occur in rocks which themselves have such structures.

Fossils.—The true nature of molecular replacement was first recognized in the study of fossils in which the substance of the original shell was altered but the form of the fossils preserved. In the early history of the study the process of replacement of fossils was termed petrefaction and quite a little is to be found in the literature in regard to it.

In his text-book of Geology,[1] Geikie describes the process in the following words:—

"*The original substance is molecularly replaced by mineral matter with partial or entire preservation of original structure.* This is the only true petrefaction. The process consists in the abstraction of the organic substances, molecule by molecule, and their replacement by precipitated mineral matter. So gradual and thorough has this interchange been often, that the minutest structures of plant and animal have been perfectly preserved. Silicified wood is a familiar example."

He then quotes the following passage from Roth[2]:

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[1] Text Book of Geology, 14 ed., p. 610.
[2] Roth, Chem. Geol. i, p. 605.

"The chief substance which has replaced organic forms in rock formations is calcite, either crystalline or in an amorphous granular condition. In assuming a crystalline (or fibrous) form this mineral has often observed a symmetrical grouping of its component individuals, these being usually placed with their long axes perpendicular to the surface of an organism. In many cases among invertebrate remains the calcite now visible is pseudomorphous after aragonite (p. 166). Next in abundance as a petrifying medium is silica, most commonly in the colloid form (chalcedony, opal), but also as quartz. It is specially frequent in some limestones, as chert and flint, replacing the carbonate of lime in molluscs, echinoderms, corals, etc. It also occurs in irregular aggregates in which organisms are sometimes beautifully preserved. It forms a frequent material for the petrifaction of fossil wood. Silification, or the replacement of organisms by silica, is the process by which minute organic structures have been most perfectly preserved. In a microscopic section of silicified wood, the organization of the original plant may be as distinct as in the section of any modern tree. Pyrites and marcasite are common replacing minerals, especially in argillaceous deposits, as, for example, among the clays of Jurassic and Cretaceous formations. Siderite has played a similar part among the ironstones of the coal-measures, where (Anthracosia, etc.) and plants have been replaced by it. Many other minerals are occasionally found to have been substituted for the original substance of organic remains. Among these may be mentioned glauconite (replacing or filling foraminifera), vivianite (specially frequent as a coating on the weathered surface of scales and bones), barytes, celestine, gypsum, talc, lead-sulphate, carbonate, and sulphide, copper-sulphide and native copper, hæmatite and limonite, zinc-carbonate and sulphide, cinnabar, sulphur, fluorite, phosphor te."

This and other similar passages will show how clearly the early geologists appreciated the distinction between preservation of internal structures and the filling of moulds left by the solution of a shell and the later filling of the opening.

Posepny describes an occurrence from Freihung in Bohemia, which admirably illustrates this point[1].

"I was struck with the numerous specimens of tree stems changed to galena; and coming subsequently into possession of such a specimen, I had a polished section prepared from it. The pieces of these stems exhibited are about 20 centimeters (8 inches) long and elliptical in sections, say 5 to 7 by 10 to 15 centimeters (2 to 3 by 4 to 6 inches). The fibre and the annual rings could be recognized on the surfaces of the fracture, but were extremely plain in polished section. Indeed, they were indicated by the cleavage of the specimens. I have thin slivers, 2 to 4 mm (.08 to 0.16 in.) in diameter and several centimeters long, representing the fibres of the original wood. The former bark is replaced by a zone of first pyrites, and then quartz grains cemented with pyrite. I do not know that the determination of the species of the wood has been attempted, but I think it should be approximately practicable. Fig. 29 is a diagram of the section of such a stem altered to galena."

In using fossils altered into ore as a criterion, distinction between solution and deposition and replacement is particularly important. In the case of larger structures, the distinction is not

[1] The genesis of ore deposits. T.A.I.M.E., Vol. XXIII, p. 314)

difficult. For more minute textural features, by one familiar with the internal structure of calcareous organisms the characteristic structure of a fossil may be readily determined by the microscope. For those who lack such knowledge and in cases where the replacing mineral is opaque like sulphides, a more satisfactory distinction between cast and replacement is necessary.

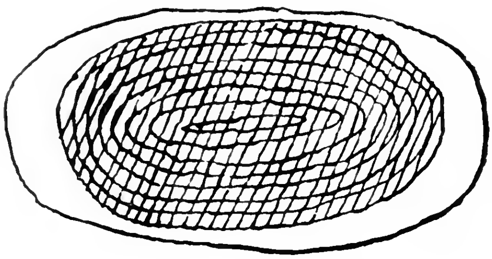

Fig. 29.—Section of a tree stem replaced with galena, Freihung, Bohemia. Shows annular rings of growth preserved in ore. (After Posepny, T.A.I.M.E. Vol. XXIII, Opp. p. 366, Fig. 84.)

This may often be carried out by the position occupied by the included fragments of unreplaced rock. In some animals the original shells, or septæ of the original shells, include spaces which are wholly, or almost wholly enclosed by shell walls. Where such shell walls are changed into a different material, possibly on account of the superior solubility of the shell material over that of the surrounding and included rock, it is obvious that such a mass of new mineral could not have formed by solution and redeposition, for the solution of the surrounding septum would have removed the support from the enclosed kernel so that it would come in contact with the outside rock mass at some point.

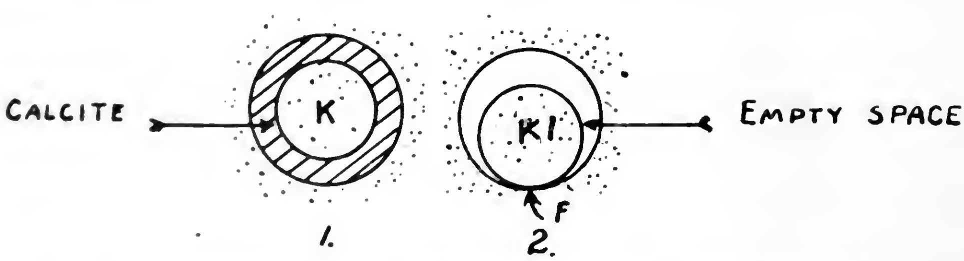

Fig. 30.—Diagram to show manner in which cast may be distinguished from replacement in the case of fossils altered to ore. K-kernel. K¹- position of kernel when shell septum is dissolved out of the rock.

Fig. 30 shows this diagrammatically. If the surrounding shell mass in 1 is dissolved the kernel K will fall to the position

"K[1]" and mineral matter introduced in solution will fill the empty space, leaving an imperfect area of mineral at the point of contact 'f'. If, on the other hand, the new mineral mass is complete it is obvious that the supporting material has at no time been removed and that the process has therefore been one of gradual replacement. No confusion arises if the shell was hollow and contained no central kernel of rock, as the space would then be completely filled with new mineral and not form a shell around a central core. Fossils therefore whose septæ have been completely preserved will often serve as excellent indications of metasomatic processes.

An additional proof of replacement is furnished when fossils have been more resistant than the surrounding rocks so that the rock has been completely changed to ore and the fossil itself left unaffected. Spurr describes an instance of this kind from Aspen as follows:[1]

"A further evidence of this process of replacement is the finding of fossils which are completely interbedded in the ore, or have been so changed as to form a part of the ore. Fig. 11 shows a mass of pure native silver, just as it was taken from the ore at the sampler in Aspen. In this silver part of a perfect fossil gasteropod is firmly embedded, and it is somewhat remarkable that the shell is still made up of the aragonite of which it was originally composed."

It is evident that fossils left in the midst of ore in this way could not have been left unsupported as would have been the case if the rock had first been dissolved away and ore introduced into the surrounding space. The fossil would then have fallen to the bottom of the cavity. The same argument applies when the fossil has been completely changed to ore provided it is surrounded by masses of ore of the same character and none of the original rock substance left to support it. (This question is further discussed under the head of unsupported nuclei).

In addition to the larger fossils altered to ore such as may be readily observed in the field, minute microscopic fossils have been retained also. One of the most interesting cases of this kind is that described by Turner from the Diadem lode, Meadow Valley, California.[2]

"A certain portion of the lode is composed of little elliptical bodies which, according to Mr. Charles Schuchert, of the U. S. National Museum, represent the silicified tests of foraminifiera of Carboniferous age belonging to the genus *Loftusia*. The shells of Loftusia were originally carbonate of lime."

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[1] Spurr. Mon. XXXI, U. G. S., S. pp. 233-234.

[2] Jour. of Geol.

Plate IV. is reproduced from this article of Mr. Turner and shows the foraminiferal test clearly outlined without the polarizer in the upper slide, the outline seemingly preserved by the unreplaceable impurities of the original rock which have not been moved from or disturbed in their original arrangement by the alteration of the mass from carbonate of lime to silica. The second figure is the same with the polarizer applied and shows that the rock is entirely made up of an aggregate of grains of secondary quartz. The different character of the lime carbonate within the fossil resulted in a slightly finer grained aggregate within than without the shell; but the perfect preservation of form is indicated rather by the disposition of the opaque inclusions.

Instances in which fossils have been altered into ore by replacement are so numerous that to cite each case is unnecessary.

Rhombic Crystalline Structure of Dolomite.—A few sedimentary rocks only are composed of grains which are distinctly characteristic. In general the grains of sediments are distinguishable as such by their water worn form only in the coarser varieties of rock such as conglomerates and these are composed of pebbles of extremely resistant material such as quartz, quartzite, etc., which resist complete replacement better than the more soluble carbonates. Of the carbonates the dolomites frequently show a partly crystalline structure so that when viewed under the microscope they are seen to be composed of aggregates of minute rhombic crystals. Plate V, taken from a specimen of shaly dolomite which frequently forms the country rock of the siliceous ore in the Black Hills of South Dakota, shows a well developed rhombic structure. Structure of the same kind is quite a striking characteristic of many dolomitized limestones and an excellent figure of one of them is shown by Harker from an English locality.[1] Rhombic structure of this kind is sometimes perfectly preserved in highly siliceous ores so that at first glance with a microscope it is difficult to detect the difference between the thin section and one cut from the original rock. An instance of this kind was observed by the writer from the siliceous ore bodies of the Black Hills. This is shown in Plate VI. In Cut A, the ore is shown in ordinary light and the sharp outlines of the rhombohedral crystals of dolomite are extremely clear. In cut B, the same

[1] Harker: Petrology for students, p. 261.

section is shown in polarized light so that the individual grains of quartz of which the rock is now composed are made evident. The entire rock mass with the exception of the original impurities in the dolomite has been changed to silica and yet the discoloration due to these minute impurities has sufficed to perfectly preserve the minute original structure.

Phenocrysts.—In igneous rocks the constituent grains possess characteristic forms only when crystal boundaries have been more or less completely developed. The phenocrysts of the porphyritic rocks, and especially the feldspars, are among the most typical structures of some igneous rocks. When such rocks are completely altered by replacement the original form of the phenocrysts is often perfectly preserved. Little or no confusion of phenocrysts with minerals developed during ore-forming processes can occur, as both orthoclase and plagioclase feldspars rarely develop as the result of ore deposition. The writer has seen porphyries in Leadville, Colorado, which have been completely altered to silica; but the silica, which has taken the place of the phenocrysts is slightly different in colour and arrangement from that which has replaced the ground-mass, so that the outline of what were once feldspar crystals can be clearly discerned in the silicious mass. Phenocrysts are often thus preserved when the replacing mineral is silica; but no instances are known to the writer in which replacement by sulphide or metallic ore minerals has resulted in their preservation.

It is important to avoid a confusion of the preservation of the form of phenocrysts in an ore mass with ordinary pseudomorphs after phenocrysts. Thus in the tin ores of Cornwall cassiterite has presumably replaced the large orthoclase crystals of the granite and perfect crystals of cassiterite after orthoclase, *i.e.*, having the form of the orthoclase crystals, are found.

Although it is probable that these cassiterite pseudomorphs have been formed by the replacement of the orthoclase, the process cannot be inferred from the cassiterite pseudomorphs, for there is nothing in the ordinary[1] type of pseudomorphism that will

[1] By the "ordinary" type of pseudomorphism the writer means that type of pseudomorphism by virtue of which one mineral appears in the crystal form of another. There is no doubt in the writer's mind that such pseudomorphs have frequently been formed by metasomatic process, but he so far

serve as a positive proof of replacement. It is perfectly conceivable that these feldspar phenocrysts can have been dissolved out of the granite by vapours charged with fluorine and the space later filled with cassiterite. The form of the feldspar crystals would then have been assumed by the tin-ore and no replacement need have occurred.

Secondary Rock Structures.

Structures which have been developed in rocks by stress and rupture are often perfectly preserved in ore bodies. A few of those that are capable of preservation only have so far been observed; but it is probable that further investigation of replacement masses will in future add greatly to the number now known. Structures of this kind are faults, joints, brecciated structures and folds, together with metamorphic structures such as gneissoid structures and schistosity. The three first, joints, faults and brecciated structures, have so far come under the writer's observation or been found in the literature. All of these structures may be developed in ore bodies after their formation so that at first it might appear that some confusion might arise in using them as criteria for the indication of replacement. It is generally possible, however, to follow them from the adjoining country rock into the ore[1] or to detect some feature about their occurrence which will readily determine whether they were present before the ore-deposition or have been produced afterwards.

Faults.—Small faults often intersect rock masses where mineralization occurs. If the original rock possesses sufficient textural variation such as banding, offsets in the layers or other structures on the two sides of the crack can usually be detected. Mineralizing waters which have gained access through such minute faults have often produced ore-bodies by replacement on either side of the fissure. Fig. 31 shows a case from one of the mines of siliceous ore near Portland, South Dakota, where the offset caused by a small fault is preserved in the ore mass. In this case the

disagrees with Mr. Lindgren and Mr. Becker as to believe that the appearance of one mineral in the crystal form of another affords no proof of the action of such a process, unless the new and the old mineral contain some common element and thus indicate chemical change rather than solution and subsequent mechanical deposition.

ore is evidently introduced after the fault structure is developed, as it is not itself affected by the displacement. There is, futhermore, no break in the continuity of the ore mass which passes from one side to the other of the former fissure without interruption. Fig. 32 shows the reverse condition where an ore-body is itself displaced along a fracture.

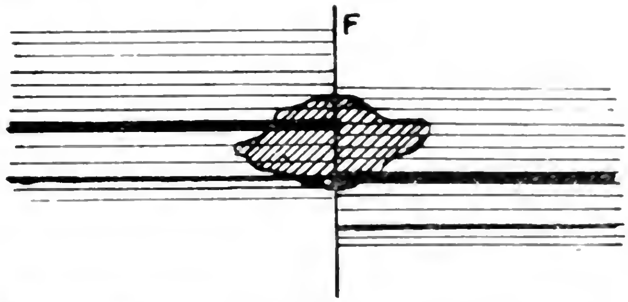


FIG. 31.—Fault preserved in ore-body. Ore-body itself not faulted, and hence formed after faulting.

Joints.—Joints or intersecting fractures have frequently been preserved in ore masses. Such jointing is distinguished from fissuring described in the previous paragraph by greater number of the cracks, their occurrence at angles to each other and the general absence of appreciable displacement along any single crack. They grade into a brecciated structure with the increase in the number of fractures but may be distinguished from it by the fact that in intersecting joints or stockworks the blocks of rock between the fissures have not been appreciably moved from their original position so that banding and other textural peculiarities of the rock pass uninterruptedly across the bounding fissures from one fragment to another.

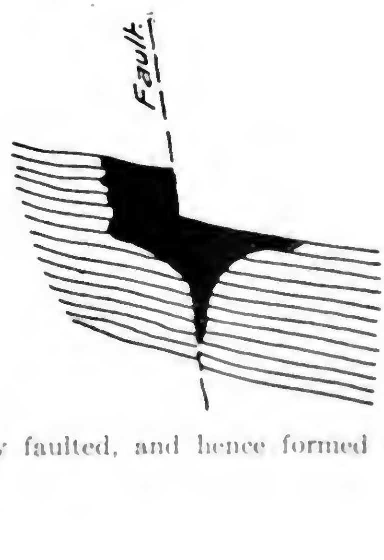


FIG. 32.—Ore-body faulted, and hence formed before the faulting occurred.

In breccias on the other hand the rock fragments have been disturbed by the movement and are set at all angles to each other and frequently lie at considerable distances from the place which they originally occupied.

Insersecting joints are preserved in two different ways. 1. By replacement which has first filled any open space and later proceeded outwards from the crack and replaced the included fragments. 2. By the replacement of infiltrated rock material which has filled the cracks before the ore was deposited.

In the former case rock structures if any be present can be traced across from one fragment to the other, although the material is now all ore. It is obvious that such a structure could be produced by the shattering of both ore and enclosing rock at the same time and that without some other evidence it affords no proof of replacement. It usually happens, however, that near the edge of an ore-body fragments have been only partly replaced so that a central core of original material remains. The original outline of the block is then angular and may be often readily discerned in the ore mass while the unreplaced core is generally bounded by a wavy, rounded line of demarcation between ore and country rock which bears only a rough parallelism to the outer and angular outline of the block.

Fig. 33 will illustrate this point. It is then evident that the mineralization has occurred later than the fracturing and the jointed structure indicates that the process has been so gradual as not to disturb this original structure. Like other larger structural features preserved in ore-masses, however, this is an indication of replacement but not a definite proof that the process has been molecular.

In the second type of preserved joints the cracks have been sealed up or filled prior to ore deposition and the mass as a whole changed into ore. In such cases the filling material of the cracks in the original rock will extend up to the ore mass and the ore itself will squarely intersect both filling and the included blocks. The outline of the blocks will be preserved by some slight difference in arrangement of the mineral grains of the ore which has replaced the filling and that which has replaced the included block.

In rare instances intersecting filled fissures in original rock masses are filled with material more easily replaced than the country rock which they intersect and replacement will affect them and leave the included blocks untouched. An instance of this kind is described by Posepny from the jointed limestone masses at Raibl, Carinthia, in which lime partitions have been changed to calamine. These occurrences are interesting; but

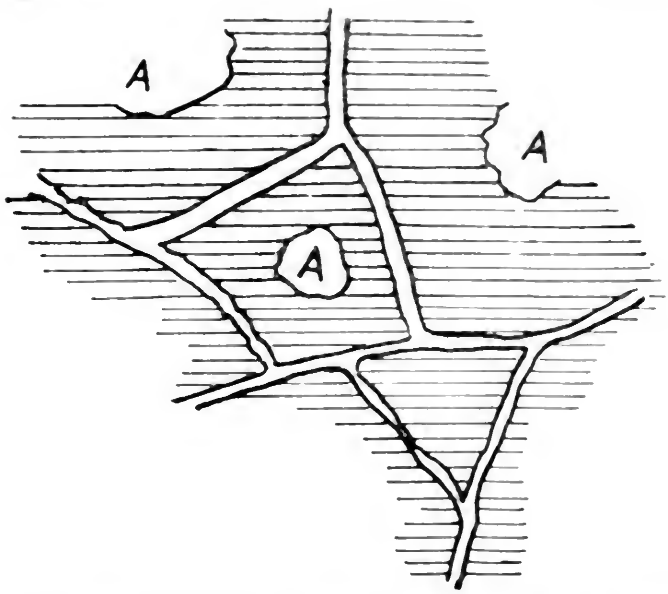


FIG. 33.—Jointed structure preserved in ore. A, A, A—unreplaced cores of country rock.

from the description given it is not evident that the calcite filling the cracks in the original rock has not first been removed in solution and calamine later introduced, and there is, in the opinion of the writer, no definite evidence to be secured from the occurrence.

Brecciated Structures.—Brecciated structures differ only in degree from intersecting joints. When they occur in insoluble and comparatively resistant rocks like granite, gneiss and quartzite, the openings developed between the fragments are generally not again completely closed up and mineralization usually begins by impregnation or the filling of the minute cavities.

Replacement of the entire mass may then occur; but the structural features, form of fragments, etc., are not often preserved so that they can be readily recognized, as the minerals which effect the replacement are more apt to be opaque minerals such as sulphides or metallic minerals which show the outlines of original rock structures very imperfectly if at all. Unaltered cores in larger fragments may be of service; but as the original outline of the fragment is rarely preserved by these minerals their relation to the cores cannot be determined and the criterion fails to be convincing.

In limestones replaced by silica it is otherwise. Limestones are often brecciated and the fragments rehealed by later deposited calcite so that over extensive areas limestone breccias occur with no appreciable open space developed in them.

Breccias of this kind are sometimes replaced by silica and the characteristic structure retained in the ore. An instance occurs in the carboniferous limestones near Ragged Top mountain in the Black Hills of South Dakota. On the north side of the mountain vertical fissures occur from which solutions containing silica and considerable gold have replaced the limestones for distances of ten, twenty or thirty feet from the fracture. All of the brecciated fragments are perfectly outlined in the ore as well as the banded structure which crosses them at varying angles. The boundary between ore and fragments is extremely sharp and the material on one side of the line of demarcation is limestone and on the other silica. All of the structural peculiarities of the limestone remain, and the appearance of ore and rock is so nearly alike that only the slightly darker colour of the ore and its greater hardness serve to distinguish it from the adjacent limestone. The fragments are often crossed by the boundary of the ore so that they are composed half of rock and half of ore.

Fig. 8 opp. page 412, is a sketch of the edge of one of these occurrences.

On the south side of the mountain similar ore-bodies occur; but the replacing material here is a dark gray mixture of silica and purple fluorite.

3. INTERSECTION OF ROCK STRUCTURES.

As already stated, replacement ore masses either pass gradually into country rock or cease abruptly so that there is a sharp line of demarcation between ore and enclosing rock.

When the change is gradual little can be learned by the insection of structures and other criteria must be sought; but when the passage is sudden another and valuable indication of replacement is available. Sharp boundaries of this kind are shown in Fig 9, opp. page 412.

All of the structures discussed in the previous paragraphs will then be abruptly cut off by the line of intersection. If the structures are also preserved in the ore we find fossils, as described by Spurr,[1] stratification planes, breccia fragments partially altered into ore and continuing uninterruptedly from country rock across the boundary into and, in the case of bedding planes, through the ore to cross again without interruption into the country rock on the other side. Instances of this kind are illustrated in Figs. 8, page 412, and Plate II. The fact that these structures are partly ore and partly rock proves beyond peradventure that the ores have been produced by a process of substitution such that no disturbance of original form has occurred. The deposition of the ore in an open cavity is shown to be an impossibility.

If the ore is composed of opaque minerals, such as sulphides or others, the continuity of rock structure is not noticeable, as the structural features are rarely perceptible in the ore itself. The passage of the ore in that case across the original rock structure in a smooth and rounded line. (See Fig. 8, opp. page 412), as is the case in some portions of the Leadville ore masses, shows that it has not been deposited in spaces of discission or rupture. The same thing is readily shown by many other criteria, such as irregularity of form, etc. Considered alone, such intersections are of no great value, as they can easily be explained in other ways; but considered in connection with those criteria which show that the ore body in question has filled in neither a space of discission nor of solution, they will serve as a useful distinction between masses of sulphides which have segregated from magmas and those which have been formed by later replacement.

4. ABSENCE OF CONCAVE SURFACES.

It rarely happens that ore bodies formed by replacement are confused with those which have filled openings caused by fissuring or the rupture of rock masses, that is, with what have been termed by Posepny[2] spaces of discission. The edges of cavities

[1] Mon. XXXI, p. 223.
[2] Trans. A.I.M.E., Vol. XXIII. p. 208.

of this kind are often jagged, and the forces which produce them cannot in any case give rise to spaces which possess the extremely irregular boundaries of many replacement ore bodies. With open spaces formed, however, by the solution of the country rock, whatever be its lithologic character, and the later formation of ore masses by deposition in them, there is sometimes difficulty in making the distinction. When the line of demarcation between ore and country rock is sharp and the transition abrupt, however, some light is thrown on the matter by the examination of solution cavities. In almost any region where limestone forms the country rock, but especially in the East where atmospheric waters are heavily charged with acids, limestone suffers greater erosion by solution than by mechanical disintegration. In almost any limestone outcrop in the Eastern States or in the surfaces of fragments long exposed, the rock may be seen to be pitted by bowl or saucer shaped concave depressions, which are usually of greater diameter than depth. Between them the separating ridges are often sharp, though sometimes slightly rounded. So common a feature of limestones exposed to atmospheric agencies is this that one comes to make unconscious use of it in the rapid recognition of limestone outcrops. In limestone caverns the same thing is perceptible although it is often rendered more obscure by the enlargement of a cavern by the falling in of portions of the roof. In all cases, then, of the solution of large caves in limestone such concave surfaces are noticeable and greatly preponderate over the convex. That cavities may be formed by solution in which this feature is not readily distinguishable must be admitted; but if an opening shows them as one of its striking characteristics it would be most reasonable to attribute it to solution. An admirable illustration of this form of solution surface is shown by Ransome in the gypsum bodies in the Enterprise mine at Newman Hill, Rico, Colorado. A careful examination of any limestone caverns will, I think, convince the reader of the preponderance of such concave surfaces.

Replacement ore bodies rarely if ever (so far as the writer's observations go), show such intersecting concave surfaces. Fig. 34 shows a concave surface produced by solution. Fig. 35 the characteristic type of boundary between ore and rock in a replacement mass.

Concave surfaces of this kind are chiefly confined to limestone; but in the open caverns considered by the writer to have been produced by solutions in the quartzite of the American Nettie mine near Ouray, Colorado, they may be also observed.

FIG. 34.—Concave depressions produced by solution.
FIG. 35.—Concavo-convex depressions produced by replacement.

5. CRUSTIFICATION.

In many epigenetic deposits of minerals, whether they be metalliferous or non-metalliferous, when formed in an open space the minerals are deposited in successive layers on the walls of the space. Changes in the character of solutions or fractional precipitation from a single solution has caused unlike layers to be deposited upon one another.

In the most perfect instances the form of the outer surface (or wall rock side) of each layer is determined by the surface upon which it is deposited; but the upper surface (surface toward the empty space) being free to develop, exhibits crystalline faces of the component minerals. We then find a succession of mineral crusts xenomorphic on the wall rock side and crystalline on the inner or empty space side. The successive crusts cover both walls and all fragments of rock which are within the cavity. When the open space is completely filled the two corresponding innermost crusts come in contact and a perfect crustified deposit is formed. If the process is arrested before completion or if widenings of the opening cause its incomplete filling the innermost surfaces of the latest crust will be covered with druses of crystals which project into the central opening or vugg. Mineral crusts of this kind vary a little in thickness, but in general they show a remarkable uniformity of thickness and of course faithfully follow the contour of the surface on which they are deposited.

Such structures when met with in fissure veins are often termed *comb structure* owing to the frequent occurrence of quartz crystals arranged with their longer or C axes perpendicular to the surface of the opening. They are not alone characteristic of fissure veins. Wherever ores develop in open spaces they are apt to form. They are never formed by replacement though they are sometimes confused with banding produced in that way. It is not necessary here to enter into the causes which produce irregularities and lack of symmetry in such layers, as these do not immediately concern the question of replacement.

Posepny was, of all the writers on ore deposits, probably the most strongly impressed with the importance of these layers and to him we owe the term *crustification* proposed to describe them. The following passage will serve to illustrate the importance which he considered them to have.[1]

"With regard to the filling, I observe, first, that the mineral deposits upon the walls of cavities, from liquids circulating within them, usually have a characteristic structure, for which I propose the name 'Crustification,' as a companion to 'Stratification.' . . . . Most frequently mineral crusts occur concentrically in regular succession, and fill the whole cavity (except the central druse), thus forming a symmetrical crustification. They cover, however, not only the cavity-walls, but the surface of every foreign body in the cavity, thus forming crusted kernels which greatly complicate the phenomenon.

. . . . As a general rule, however, *crustification is a characteristic feature of cavity filling.*"[2]

Both Church[3] and Becker[4] have objected to the emphasis that Posepny has laid upon crustification as a means of diagnosis of cavity filling, because, as they assert, it may be so exactly simulated by metasomatic processes that one cannot be certain of the origin of the structure. If the matter be examined carefully it seems to the writer that these difficulties disappear and he is strongly in accord with Prof. Posepny in the utility of this criterion. It further seems that the differences of opinion have arisen from an inadequate exposition of the exact nature of crustification and too inclusive a statement of the conditions

[1] Trans. A.I.M.E., Vol. XXIII, p. 207.
[2] The italics are not Posepny's.
[3] T.A.I.M.E., Vol. XXIII, p. 596.
[4] T.A.I.M.E., Vol. XXIII, p. 603.

under which it may be used—also by the attempt of Prof. Posepny to detect evidences of "crustification" in the descriptions of ore deposits which he had not seen.

Crustification is characteristic of *many* cavity fillings; but not all. Many fissure veins occur which are completely filled by minerals, for instance with galena, in which no deposition in layers is discernible and yet which, from the angular nature of the walls and the manner in which the inequalities of the two opposite walls fit into one another, cannot be attributed to other than the filling of cavities. Lenticular masses of quartz in schist and similar types of vein material frequently show no crustification. In the latter case it is improbable that cavities stood open at the time of the introduction of the quartz or other mineral in them; but it seems likely that they represent the loci of minimum strain and that solutions under considerable pressure deposited mineral matter in them *pari passu* with their formation. They are therefore not characterized by crustification nor are they formed by replacement. The writer therefore believes that crustification (i.e. the true crustification described below) if present is a definite evidence of the formation of ores in an open cavity—but its absence by no means indicates that a deposit has been formed by replacement.

If a deposit, therefore, is truly crustified it may safely be considered a cavity filling; if it is not crustified other criteria must be applied.

True crustification may not be in all cases distinguishable from banding produced by other causes; but such cases are not of very frequent occurrence.

If mineral is deposited on the walls of an opening in layers each crust may have a crystalline druse on one side and be adjusted to the form of the underlying crystalline druse or the irregularities of the wall rock on the other. Such relations are not, so far as the writer is aware, to be observed in metasomatic deposits. Crystalline druses occur in metasomatic deposits; but they almost invariably line vuggs caused by the decrease in volume of the original rock during transformation. The rock side extremities of the crystals never rest upon the upper crystalline surface of layers below, but interlock with the grains of similar metasomatic mineral which compose the ore. Indeed it is often possible in this way to distinguish minerals which have been deposited in these volume loss vuggs from metasomatic minerals, by the relation of their under surfaces. It often happens that volume vuggs are filled either with the material dissolved from the bed rock during the process of replacement or with minerals actually deposited by the ore bearing solutions. Such minerals either form well-defined crystal faces on their upper surfaces and no faces on their lower or completely fill the volume vugg and have their form entirely determined by the crystalline druse lining the cavity. Calcite, jarosite and fluorite occur in this relation in the Black Hills silicious ores. They are cavity fillings just as truly as those which occur in any pre-existing opening.[1]

In many cases it happens that crustification in a cavity filling is imperfect—that is, that the periods of precipitation of the different crusts so overlap that instead of each resting upon the crystalline surface of the next below the minerals are intermingled at the junction, and are consequently more or less xenomorphic in their boundaries. This is particularly common in banded veins of sulphides where fractional precipitation is such a common process in the origin of the layers.

In such cases their discordance with the stratification of the enclosing rock will show that they do not represent sedimentary banding (see Fig. 27, page 436) the preservation of their regular order of succession about included rock fragments or the existence of angular druses caused by angular spaces between fragments lined with druses will serve to distinguish them.

The most difficult cases to distinguish are those of replacement veins and filled fissures. Fissure veins are often caused by a multitude of minute fault fissures extending over a widths of 5, 10 or more feet, i.e. are formed by sheeted zones. The space for actual deposition is very small and the veins are often formed by the replacement of the tabular masses of rock which lie between the fissures. The mineral formed by the replacement of rock from one fissure will then usually coalesce eventually with that arising from the next adjoining fissure and the arrangement and material may be slightly different in the two cases, so that when the process is complete there will be bands of replacement mineral which will simulate with extreme closeness

[1] For further discussion on this point, see "Changes in volume," page 465.

the imperfectly developed crustification arising from fractional precipitation in a cavity. In some instances such cases are extremely difficult to distinguish and search must be made in the vein for angular fragments of included rock which have been incompletely replaced. If such fragments show a perfect angular form underlying the outermost mineral crust, even though they may be almost completely altered by veinforming waters, they will suffice to show that the crusts were formed in an open cavity.

The phenomenon of crustification may be carried down to microscopical determinations and definite crusts detected of a very minute character.

Lindgren[1] has described one such instance from Cripple Creek where spaces of dissolution in granite are shown to have been filled by a crustified lining of quartz.

6. Unsupported Structures.

Residual Nuclei.—In nearly every ore body which is formed by replacement there are likely to occur irregular masses of country rock or "islands" which have escaped mineralization. These may be of the same rock as that which encloses the ore or of a different rock, such as porphyry intrusions, shale bands, grains of insoluble mineral, etc., which were present in the country rock prior to mineralization. In the first instance they have remained unaffected either because the channels of access are so distributed as to render them less easily accessible, or because some seemingly fortuitous causes have diverted the flow of mineralizers in other directions; in the second because their relatively resistant chemical nature has prevented their mineralization. In many cases these masses or "islands" are supported, i.e., connected with the country rock above and below or to one side and then furnish no serviceable indication of the action of replacement—such instances may be seen in the plans of ore shoots on Plate I and are noticeable in nearly every underground map of a replacement ore mass.

In other cases it happens that not only has the country rock on all sides been replaced but also that above and below the mass so that the area of unmineralized rock is completely separated

[1] Trans. A.I.M.E., Vol. XXV, page 631.

by the surrounding ore from the mother rock of which it was once a part.

It is obvious that in any open space, whether formed by chemical action or mechanical rupture, masses of rock could not have remained suspended in mid-air until such times as ore was introduced to afford them a means of support.

In order that they can have been left undisturbed in the heart of an ore mass some process not involving the removal of structural support must be conceived. Molecular replacement by the gradual nature of its progression offers a complete explanation of these masses.

If solution and redeposition be believed to have caused them it must have involved the widespread solution of small cavities and their subsequent filling, then a new solution of more cavities and more filling and so on until the entire mass of rock was changed into ore. The process of solution must always have been arrested just short of the removal of adequate support and remained in abeyance until sufficient ore had been introduced to allow the safe removal of more rock. Furthermore with each renewal of deposition the character of depositing solutions must have been of the same chemical nature. While such a careful observance of structural safety would be a *sine qua non* to an architect or engineer it is difficult to believe that it can reasonably be attributed to mineralizing solutions.

Under these circumstances unsupported nuclei, while they cannot be regarded as proofs of the molecular nature of the process, approach so closely to absolute proof that they render this criterion of great service. This is the more important as such structures as this are often large, easily observed and not at all uncommon.

Added force is given to this criterion when the replaced rock is a sediment by the conformity of the stratification in the isolated mass with that of the country rock beyond the ore—showing that the mass is in its original position and has not been moved by crystal growth or any other cause during the formation of the ore. This is illustrated in fig. 36 page 459. Fig. 37 shows the conditions which would probably occur in a filled cavern, where pieces of country rock have fallen to the floor and where the strata in them have all angles to those of the surrounding rock.

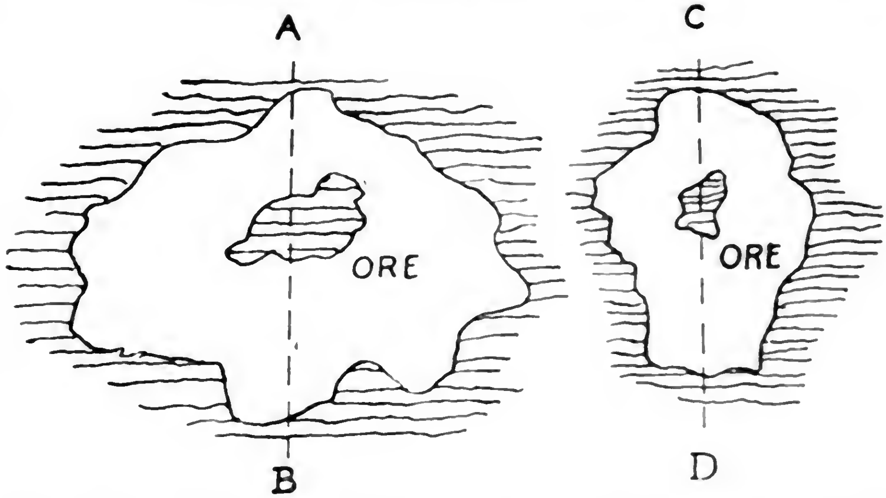


FIG. 36.—Diagrammatic sections of hypothetical ore body in limestone beds with completely unsupported nuclei of original rock entirely enclosed in ore. Stratification of the Islands shows that the limestone masses have not been removed from their original position.

In the second case mentioned, that is, where the isolated mass of unsupported rock is of a different nature from the surrounding rock, the comparatively resistant nature of the rock material has caused it to remain either unaffected by mineralization or only slightly affected.

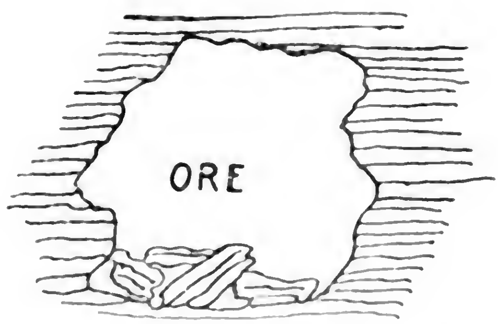


FIG. 37.—Conditions which would exist in case an empty cavern had been filled with rock débris. This would appear at the bottom of the ore mass. Also stratification in the débris at varying angles to its original position in the country rock.

Three instances of this kind can be readily cited. 1: Original quartz grains in the Black Hills refractory silicious ores. 2. Porphyry masses in the sulphide ores of Leadville, Colorado and 3. Thin shale bands in the ores of the Black Hills and at Leadville, Colo.

1. *Quartz grains.*—In the country rock of the Black Hills silicious ores—a magnesian limestone, usually slightly marbleized—isolated grains of sand frequently occur. These have presumably been derived from some igneous rock, as they are filled with minute gas and other inclusions and may easily be distinguished from the clear secondary silica which composes the bulk of the silicious ore. They can only be seen, of course, with the microscope. They occur scattered all through the ore, just as in the limestone, and *not* at the bottom of the ore mass, as would have been the case if the ore filled a solution cavity. Nor do they occur in clusters as might be the case if the ore was made up of coalesced masses formed in small solution cavities.

2. *Porphyry masses.*—Most porphyry masses are well supported, but in the large ore masses of Leadville irregular bodies of porphyry now completely changed to clay occur in the heart of the ore bodies often connected with the main porphyry intrusion by so narrow a neck of material as to show that they could not have remained unsupported if the ore had been deposited in an open cavity.

3. *Shale bands.*—In the country rock of the silicious ores of the Black Hills the bands of easily replaced dolomite are sometimes separated by beds of aluminous shales, extremely resistant to mineralization. These are often extremely thin, down to 1/16 of an inch in thickness, and yet they run for great distances through the ore, often passing completely through it. They continue in many cases over areas of hundreds of square feet or more. If these ores were originally formed by the filling of cavities the intervening lime beds must have been completely dissolved out leaving the shale bands as a sort of "grizzly" supported in perfect equilibrium and without the slightest disturbance over very great areas. It is therefore evident that the process of replacement must have operated in these masses, as that is the only method of deposition by which the rocks could have been changed to ore and support at no time removed. The same characteristics can be noted in some of the Leadville ore bodies. Those which occur in the blue or carboniferous limestone and in the upper white limestone do not show this feature, but at the base of the white limestone where it passes into quartzite the limestone is interrupted by many highly aluminous

porcelain-like beds of shale and where these beds have been replaced by ore the shale bands have remained unaffected within ore mass. This is especially well shown in the lowest ore mass in the Tuscon mine on iron Hill where the shale beds remain unreplaced in much of the ore mass.

Fossils.—Spurr has described a fossil from the ore of Aspen, Colorado, already mentioned on page 443 completely surrounded by ore; but not itself replaced.

It is obvious that this fossil could not have remained unsupported in mid air any more than the other structural masses mentioned above.

Phenocrysts.—When porphyritic igneous rocks are replaced the phenocrysts are sometimes more resistant to replacement than the body of the rock and sometimes persist in the ore as soft, whitish, clay-like crystals with original form unimpaired and substances only partially affected by mineralization.

It must of course be remembered that in a rock other than limestone the process of replacement is frequently incomplete, that it affects only some of the minerals of the rock. Solutions could, therefore, have easily dissolved and removed some of the minerals of the rocks and left a matrix which was porous but perfectly supported into which ore was later introduced. This of course would not be replacement but simply solution and redeposition. In order that phenocrysts should furnish, as unsupported nuclei, a definite indication of replacement the change from rock to ore must have been so complete as to leave none (or extremely little) of the original substance to support the crystals. Phenocrysts are much more serviceable when preserved in ore than as unsupported nuclei.

Earlier formed Crystals in the Ore.—Many sulphide ore masses show complete crystals of quartz pyrite, galena or some other mineral perfectly bounded on all sides and now completely surrounded by either a second generation of the same mineral or other ore minerals.

Lindgren gives two illustrations of thin sections of silicified limestone from the Elk Horn mine, Montana, which may be used to illustrate this point. These are reproduced in Figs. 19 and 20. In the first of them quartz crystals are seen developing in the limestone. In the second such quartz crystals are also seen in outline with all of the intervening lime replaced. They are not clustered together at the bottom of the ore mass nor supported by contact with contiguous crystals, but are separated off by themselves and are an excellent case of unsupported structures.

The silicious ore of the Black Hills often contain perfect crystals of pyrite, the Jasperoid masses (masses of secondary silica) of the Ibex mine in Leadville often show complete crystals of pyrite imbedded in the silica. Many replacement ore bodies show honeycombed quartz at the surface with cavities having the form of pyrite crystals, which have been dissolved out by oxidation process. Instances of this kind from sulphide ore bodies are too numerous to need separate mention.

It is evident that these perfect imbedded crystals were either formed first and existed as replacements in the country rock or were formed later. If later they must have replaced the ore mass itself. It seems probable, at least in limestone masses where the country rock is so much more soluble and easily replaced than the ore, that they represent the first mineralization, replacing the country rock as a sort of advance guard of the main mineralization. The rest of the rock was then replaced, leaving these earlier replacements completely surrounded by ore. In this case they serve just as other unsupported structures do to prove the gradual nature of the substitution of ore for rock. If they are later introductions they cannot have been formed by any process except replacement of the ore itself, for they are perfect crystals on all sides and show no evidence of having had a supporting surface upon which to grow. If both complete crystals and enclosing ore are of the same mineral the complete crystals are even more certainly the earlier replacements. When for instance perfectly formed pyrite crystals are embedded in finer grained pyrite, as in Leadville, it seems chemically improbable that a mineral should have replaced itself. In any case they show that either they themselves were formed by replacement or on the other hand, the surrounding mass of ore has been formed by that process or both.

Care must be taken in using this criterion to distinguish between the *nearly perfect* crystals that one sees in the crustified or imperfectly crustified linings of cavities whose interstices have been filled with other deposits from solution and the *perfectly* formed crystals which occur embedded in masses of ore. Generally, evidence of some imperfect face, where growth on a wall has occurred, can be found, or if not, then the evident crustified nature of a deposit will make the origin of the seemingly perfect crystals manifest. Confusion might also occur with igneous ore bodies formed from magmatic segregation. Such are supposed by some authors to be the nickeliferous pyrrhotites. Generally, the nature of the ore occurrence will be such as to show whether or not it may be ascribed to magmatic segregation and this point once settled the criterion becomes again available.

7. FORM AS A CRITERION.

As a criterion for the recognition of ore masses formed by replacement form, while it will not serve as a sufficient proof in itself, will be a strong *a priori* argument for this origin. A glance at any of the cuts of replacement bodies in limestones, as in Plates I and II and Figs. 5 and 11, will serve to prove beyond doubt that cavities of such shape could not have been produced by any mechanical process. Rupture, faulting and fissuring of rocks could certainly not have produced them.

The only remaining processes then to which irregular openings of such kind can reasonably be attributed is solution. If we can conceive of waters first dissolving out great caves in limestone, or in rocks of greater resistance to solution, we might have openings of this kind formed. An examination of any limestone cavern will furnish cavities whose irregularity of form, distribution, relation to fractures in the rocks, etc., resemble to some extent replacement ore bodies. It was for this reason, indeed, that early opinion (of Eureka, Nevada, Arnold Hague, Mon. XV, p. 308, 311, 316) attributed all such irregular masses in limestone to the filling of caves formed by surface waters.

There are many facts which show that this solution and redeposition would have been impossible. The first argument advanced was that ore deposits, such for instance, as those at Leadville, Colorado, and others were formed at a geological age when a very heavy covering of still uneroded rock lay above the rocks which now enclose the ore bodies. Ten thousand feet is estimated as the depth of cover in Leadville. Surface waters do not form caves below the level of permanent water level so that their formation in such manner could not have occurred unless depression to great depths occurred after their formation and evidence against such a depression is overwhelming.

Further evidence is afforded by many of the minerals which occur in such ore bodies for many of them show aggregations of minerals that are stable only under the high pressures and temperatures that obtain at depths very far below the level of permanent ground water.

If then open cavities have been formed and later filled with ore the solution must have been performed by uprising mineral waters, presumably different waters from those which deposited the ore masses themselves. Posepny[1] was of the opinion that mineral waters have in many cases dissolved out such openings and even supposes them to have forced their way upward through rock masses without the aid of any channel of access.

In the majority of ore deposits now ascribed to replacement the other criteria, unsupported nuclei of limestone, or other original rock, the original sand grains of the rock, the formation of perfect crystals of one or more minerals in the ore now surrounded entirely by ore, preservation of structure, etc., have one or all shown beyond peradventure that the ore bodies could never have been formed in open cavities. There are, however, some few cases in which the hypothesis of Posepny seems true, for crustification of minerals on the walls of irregular cavities conclusively proves that the process was one of solution and later deposition.

The lead zinc ores of Wisconsin (see Fig. 27) described by Chamberlin, are instances of this, the ores of Rézbanya, described by Posepny, the gold ores in the American Nettie mine in Ouray, Colorado, in part represent such an occurrence. Solution and redisposition are also described by Lindgren and Ransome from Cripple Creek. In the upper oxidized portions of any ore deposit in soluble limestone where surface waters can penetrate, open caves lined with crustified oxide ores are often found. They occurred in Eureka, Bisbee, and are even described by Blow from Leadville; but in none of the sulphide masses can any such occurrences be noted.

Another very strong argument against the formation of these large irregular masses of ore as fillings of solution caves in limestone is the absence of cave detritus in the ore body. In any

[1] Trans. Am. Inst. Min. Engs., Vol. XXIII, p. 216.

incompletely supported cavern fragments of the rock forming the roof fall from time to time and an accumulation of debris occurs on the floor of the cave. This is heaped up in an irregular manner, the bedding planes lying at all angles according as the fragments rest after their fall. Such detritus was actually found in the cave deposit of the Copper Queen Mine where caves formed by surface waters in the upper workings occurred lined with crustified linings of malachite and aruzite. But in none of the large ore bodies that have come under the writer's observation, nor in any whose description he has read can such detritus, gathered at the bottom of the ore masses be observed. Figs. 36 and 37, page 459, are diagrams illustrating the point.

In conclusion then, it may be said that irregularity of form, unless the ore mass shows a definite crustification on the walls, or unless distinct intersecting concavities be observable, is in itself, a very strong, though not necessarily conclusive, proof of the formation of an ore mass by replacement.

8. Cavities Left By Decrease In Volume.

It rarely if ever happens that material substituted for country rock is of equal volume with the original material. The varying densities of minerals and proportions of the new and old minerals taking part in the reactions usually result in a very marked change in volume. Lindgren has shown that formulæ for rock alteration may be written indicating both increase and decrease in volume. It is difficult to conceive how a mineral of greater volume than that replaced can be introduced without a marked compression of the adjacent mineral grains, and such pressure should, if present, show under the microscope in wavy extinction and other recognizable optical anomalies. These have never to my knowldege yet been detected, and it might therefore be supposed that increase in volume of actual substance has not occurred. Where porosity of original rock, however, is large, a mineral of greater volume might be conceived to form by the occupation of all the available pore spaces. Replacement might therefore easily occur in porous sediments when a considerable increase in volume was involved without producing strain phenomena in the constituent minerals of the rock.

A decrease in volume involves no difficulties, and may find expression in a porous rock as a result of the substitution of minerals of greater for minerals of less density. Thus, if in a limestone of 3% porosity galena be substituted for calcite, and actual measurements of volume of the resulting rocks show a porosity of 30%, a decrease in volume of 27% has occurred.

If the molecular volumes of the minerals which are often substituted for limestone be examined and compared with those of the component minerals of the replaced limestone it will be found that the molecular volumes of the new mineral are sometimes less and sometimes more than those of the original rock. This is shown in the table given below:

EUROPE.

Minerals In Limestone		Specific Gravity	Mol. Weight	Mol. Volume
Apatite	$3CaP_2O_5.Ca(Cl,Fl)_2$	3.22	501.22	135.7
Kaolinite	$H_4Al_2Si_2O_9$	2.5	259.05	103.62
Glauconite	$Fe_9K_5AlSi_3O_{34}.(OH)_3$			
Carbon (Graphite)	C	2.09	12.00	57.41
Magnetite	Fe_3O_4	5.00	224.06	44.81
Calcite	$CaCO_3$	2.72	100.07	36.78
Rhodochrosite	$MnCO_3$	3.7	134.99	36.48
Siderite	$FeCO_3$	3.9	116.02	29.75
Magnesite	$MgCO_3$	3.0	84.28	28.09
Quartz (Igneous)	SiO_2	2.2	60.40	27.45
Rutile	TiO_2	4.25	80.15	18.06
Minerals In Ores				
Stibnite	Sb_2S_3	4.52	337.07	74.35
Gypsum	$CaSO_4.2H_2O$	2.32	172.17	74.21
Barite	$BaSO_4$	4.72	233.50	49.41
Scheelite	$CaWO_4$	6.0	288.90	48.15
Chalcopyrite	$CuFeS_2$	4.3	183.76	42.73
Wolframite	$FeWO_4$	7.5	304.85	40.64
Galena	PbS	7.7	238.99	31.04
Arsenopyrite	FeAsS	6.27	163.10	26.01
Sphalerite	ZnS	4.0	97.48	24.37
Fluorite	CaF_2	3.25	77.89	23.97
Quartz (Vein)	SiO_2	2.6	60.40	23.23
Pyrite	FeS_2	5.2	120.16	23.11

In cases where the molecular volume of the new mineral is less than that of the mineral replaced, it is obvious that if an equation be assumed for replacement involving only the substitution of one molecule of new mineral for one molecule of original rock a slight decrease of mass would result. It frequently happens, however, that the replacing mineral shows a much less or much greater decrease in volume (as shown by the volume vuggs or cavities in the replacing mineral) than is called for by this difference, and it is quite evident that the equation assumed for the change may involve different numbers of molecules on its two sides. This is especially evident when a mineral like quartz replaces limestone, and the vuggs or cavities left in the resulting material are in greater abundance than the difference in molecular volume would seem to justify. Again, it is frequently the case that the molecular volume, such as that of wolframite, is greater than that of the original mineral and yet a very marked decrease in total volume has occurred. This is seen in the wolframite deposits of the Black Hills, South Dakota, which replace limestone. Lindgren[1] has shown in great detail detail how the nature of the equation will affect the change in volume theoretically calculated. It is furthermore impossible to calculate this change exactly from analyses, unless some one element has persisted unchanged in the process, which does not often happen.

The observed facts, however, whatever may be the theoretically calculated change, show that in nearly all silicious replacements and in by far the greater number of metallic replacements there has been an appreciable and often very marked decrease in the volume of the rock.

This finds expression in widely distributed cavities in the ore into which crystals of the latest formed ore minerals project. These cavities are usually without regular form or orientation, having all possible forms and being set at any angle to the original rock structures and to each other. They are frequently of extremely intricate form, being almost labyrinthine in their complexity.

Such a reduction in volume is further borne out by the fact that in most cases the space occupied by the new material is of exactly the same volume as before alteration. That is, the rock mass itself has not been condensed into a smaller space. Thus, in Leadville the rock structures, stratification, porphyry limestone contacts, etc., are not at all disturbed during mineralization.

Likewise in the silicious ores of the Black Hills the strata

[1] Trans. A.I.M.E., Vol. XXX, p. 591.

run directly through the ore, and where two unmineralized layers run through the mineral mass without silicification the shale bands are no nearer together nor further apart than before the replacement. This is illustrated in Figs. 38 and 39 and 10.

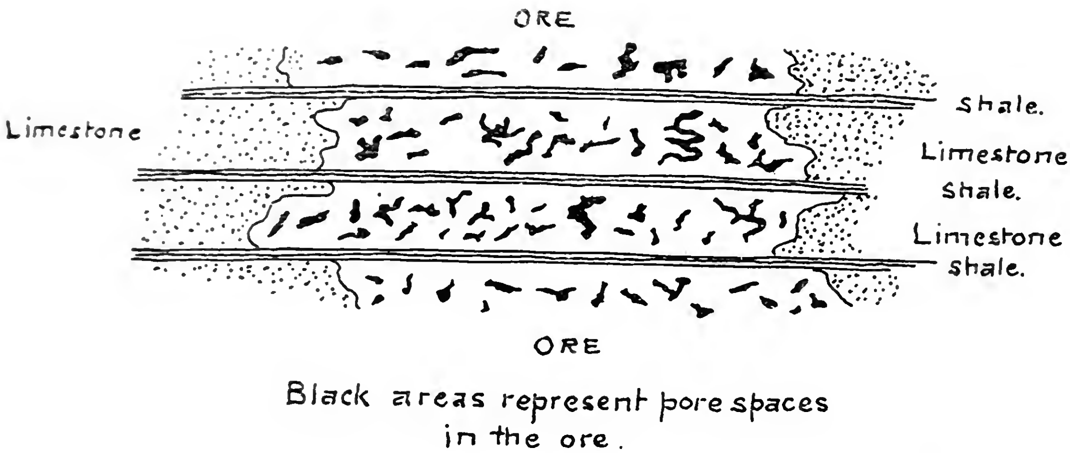


FIG. 38.—Sketch of ore-shoot in Black Hills, showing shale bands in ore and pore spaces caused by decrease in volume. Size of pore spaces exaggerated. Lack of distortion of shale layers shows that there is no compression of original rock into smaller space. Pore spaces show a decrease in total volume.

Pores of this kind or "volume vuggs" are often of great value in detecting replacement. They cannot be, of course, regarded as very serviceable criteria in determining the molecular nature of the process; but they are frequently so characteristic a feature that they will lead one to look for other criteria of a more certain character.

It is important that they should not be confused with interspaces between crustified layers which line cavities. When mineral crusts are very definite there is usually no difficulty; but when crustified layers are imperfectly formed the relation of the openings to fragments of country rock should be determined. Volume vuggs are much more irregular in shape than cavity vuggs, are rarely if ever angular in outline, are generally more intricate and bear much less definite relations to wall rock, included fragments, etc., and are usually more widely disseminated in an ore mass. In some instances the distinction is difficult to make and this criterion then fails; but in the majority of cases the origin of the openings is at once evident.

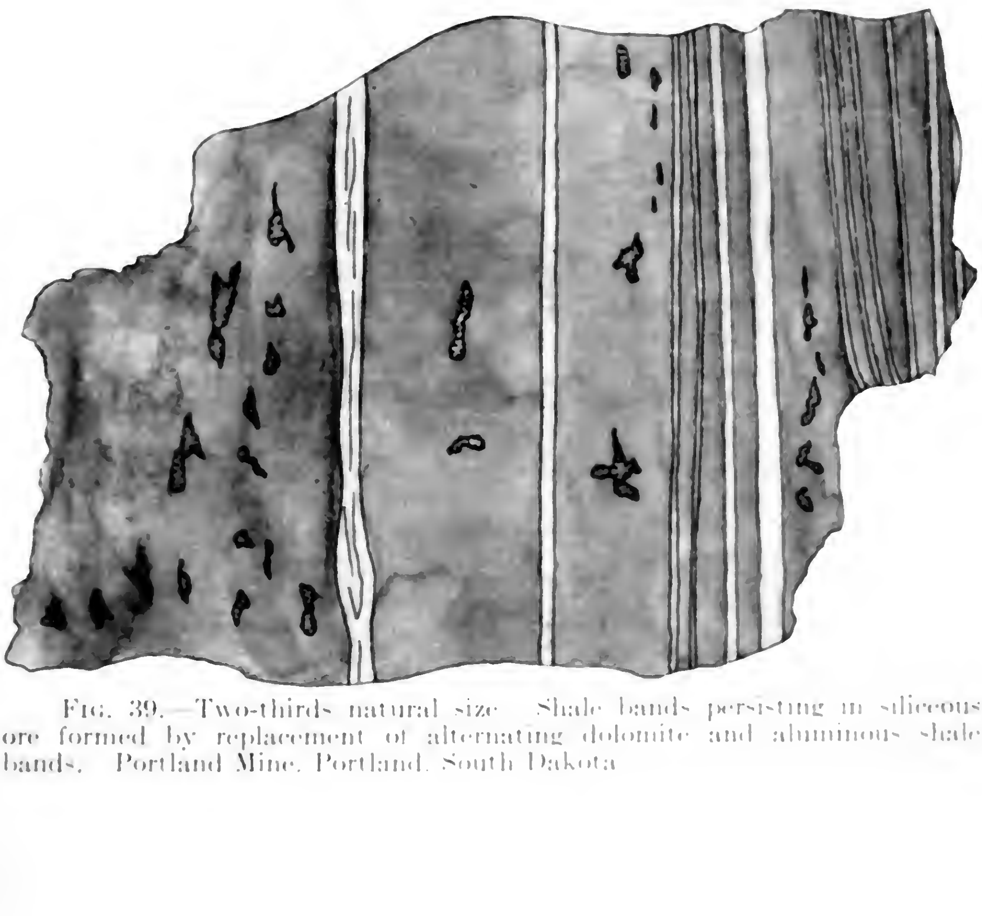


FIG. 39.—Two-thirds natural size. Shale bands persisting in siliceous ore formed by replacement of alternating dolomite and aluminous shale bands. Portland Mine, Portland, South Dakota.

9. EXCESS OF VOLUME OF NEW MINERAL OVER PORE SPACE OF COUNTRY ROCK.

In many dense igneous rocks it frequently happens that disseminated particles of ore are introduced in the vicinity of a fissure or opening. It may be an easy matter to determine whether they are epigenetic or igneous in origin; but the distinction between impregnations, i.e., particles of ore deposited in original pore space, and disseminated replacements is more difficult. In such cases, if the average porosity of the country rock be determined and then the total volume of the new mineral be determined, if the volume of the new mineral is in excess of the available pore space some of the rock matter must have been removed to make room for it. This, of course, gives no clue as to whether such increased space was caused by replacement or by the formation of minute and widely scattered spaces of dissolution; but it will serve to direct the investigation toward the discovery of those criteria which will determine this particular distinction.

V.—PHYSICAL CONDITIONS UNDER WHICH REPLACEMENT CAN OCCUR.

Temperature and Pressure of Replacing Solutions.—It has not been the purpose of this paper to enter into a detailed discussion of the chemical problems of replacement but rather to describe characteristics of replacement deposits and to attempt to establish some criteria by means of which replacement may be recognized. It is necessary, however, to describe briefly the different physical conditions under which it may occur in order that some of the more complicated cases, involving contact metamorphism and the consequent complex changes in volume of the resulting mineral masses, may not give rise to confusion.

Replacement has been brought about unquestionably by the substitution of mineral matter in solution for mineral matter in the solid condition, the process involving both the removal of the original material and the deposition of the new. This mineral matter in solution may be introduced into the rock under four different conditions:—

1. It may be in solution in surface waters which have dissolved it from the upper portion of a deposit and carried it downward through cracks and fissures. It is then under low pressure and at surface temperatures except in so far as the heat of chemical re-action raises the temperature during the process of replacement. Replacement by secondary oxides and much secondary sulphide enrichment are believed to have been produced in this way.

2. It may be in solution in sea water or water of lakes and streams and replace soluble carbonates which are accumulating on the sea bottom. It is then cold; or, more exactly, at ocean or surface temperature. Mineral matter in this form of solution is supposed by C. H. Smyth, jr., to have been responsible for the formation of the Clinton iron ores.

3. It may be in solution in so called "juvenile" waters which were hot ascending waters and to which the bulk of our normal ore deposits, usually termed hydrothermal deposits, are, in the writer's opinion, to be attributed. Solutions of this kind are probably highly heated and under considerable pressure, but are below the critical temperature and pressure of water and consequently aqueous. They operate under conditions of temperature and pressure insufficient to produce contact metamorphism. Hydrothermal replacement is supposed to have produced such deposits as those in the Black Hills, Leadville, Colorado, and possibly at Eureka, Nevada.

4. It may be in solution in water which has been raised above the critical temperature and pressure so as to be in a vaporous condition. Such solutions are presumed to arise as emanations from magmas. They are not only hot themselves but they operate on highly heated rock masses. They arise chiefly in the neighbourhood of intrusive igneous masses. If limestone or calcareous rock is present their action is supplemented by intense contact metamorphism and rendered excessively complex by volume changes which are independent of simple metasomatism. If limestones are absent they produce deposits commonly called pneumatolytic deposits.

Classification of Replacement Deposits According to Physical Conditions.—If these conditions of solution be expressed in terms of classification we may derive the following:

Replacement.

- **Thermal** (By solutions at elevated temperatures greater than surface temperatures).
  - 1. Pneumatolitic Replacement (By solutions at temps. and pressures greater than critical temp. of water.
    - *a*. Contact metamorphic replacement.
    - *b*. Pegmatitic replacement apart from contact metamorphism.
  - 2. Hydrothermal Replacement (By solutions at temperatures and pressures less than critical temperature of water.
- *Athermal* (By solution at low temperatures at or less than surface temperatures.
  - 3. Contemporaneous Replacement (By seas, lakes and streams during deposition).
  - 4. Surficial Replacement (By descending meteoric waters).
    - *a*. By oxidation products.
    - *b*. By secondary sulphides

Pneumatolytic, hydrothermal and contemporaneous replacement are primary processes, that is, they have operated to form ore bodies previous to the action of superficial alteration or change.

Surficial replacement is entirely secondary.

The criteria for the recognition of replacement which have been discussed in the preceding pages apply only in minor degree to contact metamorphic types, and are mainly concerned with the hydrothermal group of deposits. The consideration of the other and more complex forms of contact metamorphic replacement is reserved for fuller discussion in a more detailed paper now in preparation.

GEOLOGICAL PROBLEMS PRESENTED BY THE CATSKILL AQUEDUCT OF THE CITY OF NEW YORK.*

By J. F. KEMP, D.Sc., Columbia University, New York.

For ten years and more the authorities of New York have foreseen the day when the present water supply would be unequal to the city's demands. Now that the population has almost reached five millions the matter is becoming more and more pressing and every effort is being made to provide against the call of the future. A great aqueduct is in active construction, involving many miles of pressure tunnels and presenting not a few problems in whose solution the geologist has been of great service to the engineer and the contractor, who have so harmoniously cooperated that pure science has profited no less than applied. A few words of general introduction will make the situation clear.

The city of New York now embraces within its limits Staten Island, the western end of Long Island, Manhattan Island and a portion of the mainland of New York State, which is called the Borough of the Bronx. There are thus two islands with deep rivers on all sides; a portion of a third island, and a portion of the mainland which is, however, a narrow projection between the Hudson River on the one side and the State of Connecticut on the other. At present Staten Island is supplied by its own rainfall and brings in no water from the outside. Brooklyn and the Borough of Queens, draw their supplies from groups of driven wells in the sands and gravels of central Long Island. They are, however, now restrained by the courts from taking more and thus lowering the general level of the ground-water. Manhattan and the Bronx bring their supplies from the east shore of the Hudson north of their boundaries. But counties possessing streams which have not yet been tapped object to the removal of their supplies, and

*Abstract of a lecture delivered at Annual Meeting, Quebec, 1911.

neighbouring states have passed legislation forbidding the taking of water from their areas as it is needed for their own citizens. New York is also forbidden by law from intercepting the head-waters of streams which would otherwise cross state boundaries. Of necessity the city's engineers have been driven to the Catskill mountains and have taken the most available of the large streams, Esopus creek. The Esopus rises amid the high summits and flowing in a general way southeast nearly reaches the Hudson at Kingston; but it then takes a peculiar northeast bend and avoiding its apparent natural mouth finally enters tidewater at Saugerties, ten miles to the north. Its upper waters are so related to Schoharie creek, a tributary of the Mohawk, that the Schoharie supply can later on be added to the Esopus by a tunnel through the divide. The Esopus in its lower, southeastern course passes through an open section of country and then through a narrow and precipitous, post-glacial gorge, the two furnishing an excellent site for a dam and a large reservoir above it at such an altitude, (590 feet above tide), that the necessary head is afforded for forcing the water to New York.

The gorge is in the shales and flagstones of the Ithaca, Sherburne and Hamilton members of the Devonian. Its sides have supplied suitable stone for the masonry of the dam and from quarries near the site. Before the final location of the dam was selected borings were put down, which soon revealed the preglacial channel now choked with drift and at one side of the present stream. Its bottom was some fifty feet below the present bed-rock of the creek. When the dam is completed, the engineers will take the water from a point well back of it and near the bottom of the reservoir. The water will pass in siphons through the dam and will rise in a series of huge fountains outside of it before starting on the way to the city. By this means, dead, stagnant water will be avoided in the reservoir itself, and the water will be thoroughly aërated before entering the aqueduct. Fifty feet of head will be utilized for the siphons and fountains.

The aqueduct itself has furnished the chief field for the geologist. Many tentative lines were surveyed and tested before the final choice was made. The great object has been to keep the water as much as possible on grade, so that the construction can be "cut-and-cover;" but it has been necessary to cross the wide valleys of Rondout creek, the Walkill river, and the narrow valley of Moodna creek, west of the Hudson. The valley of the great river itself must then be traversed, after which on the east bank only some small creeks are encountered which present comparatively few difficulties.

The valley of Rondout creek makes necessary a tunnel nearly seven miles in extent and one which crosses an extremely complex geological section. Before discussing the strata, however, it should be remarked that an aqueduct tunnel below grade is different from the usual ones with which we are familiar. Its bursting pressure is from within, so that it is apparent that when we deal with a circular column of water, roughly 15 ft. in diameter and under a head of 500 ft. or more, we have an enormous interior surface, exposed to a pressure of about 250 lbs. to the inch. It becomes necessary therefore for the geologists to keep the tunnel in firm, solid rock as far as possible and under good cover.

Where the cut and cover construction necessarily ends on the west side of the valley of Rondout creek, the bedrock is the Hamilton shales and flagstones. They have a flat dip to the northwest as do all of the strata in the section, barring small rolls and overthrust faults. The section is as follows. Opposite each member is placed its thickness as now determined by the borings and the tunnel. At the outset, however, we only knew these thicknesses in a general way:

	Feet
Hamilton shales and flagstones.	500
Onondaga cherty limestone.	200
Schoharie and Esopus shales.	800
Oriskany and Port Ewen siliceous limestone.	200
Becraft firm, pure limestone.	100
New Scotland shaly limestone, ...	100
Coeymans cherty limestone.	100
Manlius, earthy limestone with several subdivisions, Manlius proper, Rondout cement, Cobleskill, Rosendale cement, Wilbur.	80
Binnewater sandstone	60–100
High Falls shale	67–100
Shawangunk Conglomerate.	280–400
Hudson River slates.	2500

The middle members from the Coeymans through the Port Ewen constitute the old Helderberg limestones of the early survey. Thus the Coeymans is the Lower Pentamerus; the New Scotland is the Delthyris shaly; the Becraft, the Upper Pentamerus.

The Manlius is in part the old Tentaculite limestone; but as the Manlius represents the closing Siluric formations, its subdivision has been of much stratigraphic importance.

A series of borings were put down along the line of the tunnel as soon as the surface geology had been carefully plotted. The borings revealed several interesting things not otherwise visible. First, two buried channels were shown, one at the western end of the section called the Kripplebush, where, under the high ground, one would not have anticipated such a depression; since the surface stood at 360 ft. the bed-rock was struck at 75 ft. above tide. Not only was there a buried channel but the relations of the cores revealed also a vertical fault of 200 feet displacement, such that the Onondaga limestone was out of its natural position by 200 feet or just its own thickness. The second buried channel lay beneath Rondout creek itself. The present creek flows at 187 ft. above tide, whereas its pre-Glacial predecessor's rock bottom is now —10 ft.

Besides the fault at the Kripplebush channel the drill also revealed others of a thrust character at five additional places in the Rondout valley.

An important problem that concerned both geologists and engineers was the volume of water that would probably be encountered in the various formations. The geologists soon concluded that the Binnewater sandstone and the High Falls shale were the danger points, a forecast which has been abundantly corroborated by experience. The engineers allowed for this in a very ingenious way by so arranging the depth of the tunnel that, when driving from west to east, they would cross the wet ground on an up-grade. The water thus ran down to the pumps already installed and away from the working face.

Once across the Rondout the tunnel rises by a shaft to grade in the Shawangunk range, whose crest it penetrates by a grade tunnel and once on the east side winds along with "cut and cover" past Lake Mohonk until the plunge must be taken to traverse the broad and fertile Walkill valley.

In the Walkill depression no very serious difficulties were encountered. The rocks are uniformly Hudson River slate, with some hard beds of sandstone. Two interesting buried channels, were encountered, one, on the west beneath a surface altitude of 390 ft., has its bedrock at 285; the other's bed-rock stood at 67 with the surface at 180.

Along the east side of the Walkill valley the aqueduct winds with cut and cover for many miles, passing back of the city of Newburgh and finally reaching the north flank of the Archean Highlands of the Hudson. Before it could cross to the ancient gneisses, however, it encountered the valley of Moodna creek, where the drill revealed another buried channel. The surface stood at 300 and the bedrock at −50 feet, but it was not specially troublesome; and with a short tunnel the water can flow at grade around the northern slopes of Storm King mountain until the valley of the Hudson itself is reached.

The crossing of the Hudson has presented one of the most difficult problems. Before the location was selected very careful studies were made and various tentative lines of borings were put down from near Poughkeepsie to West Point*. All showed faults in the strata or at least a passage from one formation to another, except the one at Storm King, where the Hudson is very narrow and where the rocks are uniformly granite from one side to the other. Because of this geological consideration and because the approach to the Storm King crossing was so much more advantageous, representing a saving of a million dollars in construction work, west of the river, this line was finally chosen.

In the earlier studies of the situation it was believed that the rock-bottom would not be found at a prohibitive depth. The Storm King granite is the hardest rock crossed by the Hudson in its entire course from Albany to the sea. As the excavation of its valley was attributed to water—current beliefs at the time not attaching much under-erosion to glacial ice—the inference followed that the Storm King granite was the most likely of all the rocks to form a reef. Borings, which were carried on from lighters and with great difficulty because of the swift tides and the shipping,

*These are described in detail by the writer in the American Journal of Science, Oct. 1908, 26, 301-23. The latest data are in Bulletin 146, p. 81, N.Y. State Museum, by C. P. Berkey.

soon showed that the bedrock was unexpectedly deep. The final evidence has demonstrated that at the deepest point it is somewhere between 750 ft and 900 ft. below the surface of the river. The aqueduct will cross by two shafts and a connecting tunnel at a depth of 1100 ft. The heading has already been turned from the shafts and the work is advancing rapidly beneath the river. Diamond drill cores have shown perfectly solid rock all the way across. One curious feature of the granite as revealed by the excavations has been the intense strain under which it stands. When surfaces are exposed in the shafts and tunnels, they must be protected, else they shell off with explosive violence. Therefore the permanent lining follows as closely upon the advance of the face as is practicable.

The great depth of the bedrock has reorganized our ideas upon sub-glacial erosion. The greatest depth to bedrock known to us in the Hudson above the Storm King as shown by a diamond drill boring is 223 ft. Wash borings are of no decisive value in determinations of this kind because we never know whether they have grounded on a boulder or on bedrock. In the explorations connected with the Pennsylvania Railway tubes under the Hudson opposite 33rd St. New York, the bedrock was found at 300 ft. There is a gap of over 1,000 feet between the borings in the middle of the river and there may be a notch or gorge within this stretch. Otherwise we have the bedrock bottom of the river at least 500 ft. higher opposite New York City than it is 40 miles north at the Storm King crossing. We have therefore inferred that the tongue of ice which crowded through this granite gorge scooped out the rock bottom for five or six hundred feet and over-deepened it. As the ice sheet lost force toward the region of the terminal moraine to the south, it lost its eroding power and the bedrock remained at greater attitudes. The valley of the Hudson above the Storm King crossing favours this view, since it is broad and is so terminated by mountain ridges on the south as to crowd the ice into the narrow pass.

In the study of the problem, the possibilities of crustal warping with a sinking on the north, have been considered; but the Cretaceous peneplain, which is one of the most marked topographic features of the region, gives the assumption a decided negative. We find also no evidence that the Hudson cut across its present western bank and ever reached the sea by a buried channel now beneath the Hackensack meadows of New Jersey.

The engineering features of crossing the Hudson thus consist in sinking two shafts on each side of the river and then driving a tunnel across at a depth of 1,100 ft. Since, however, the water will reach the Hudson valley with a head of 400 ft. the pressure on the inside of the tunnel will be nearly 750 lbs. to the square inch. This is balanced by the crushing pressure on the tunnel which is much greater; but as against outward seepage, a lining of extremely fine cement must be provided.

Once across the Hudson the aqueduct passes toward the city by predominant cut and cover. The several smaller valleys which have to be tunneled present no great difficulties; but the borings have revealed the anticipated buried channels, which point to a time when the continent stood decidedly higher with regard to the sea, than it does now. The borings have thus added greatly to our geological knowledge.

The new aqueduct is so planned that it can feed into the present Croton reservoirs; but its ultimate goal is a great new storage basin at Kensico, on the Harlem R.R., above White Plains. From this the water will pass to a smaller Hillview reservoir, just on the northern edge of the city limits. It will still have 295 feet effective head with which to serve the mains. A great tunnel will carry it beneath Manhattan Island and across the East River just south of Grand St., to Brooklyn. The remoter future will see it continuing still farther south by tunnel in the glacial drift and across the Narrows of New York Bay, in the terminal moraine to Staten Island. While two or three years may suffice to have it reach the Croton reservoir, several times as long will be necessary to reach Brooklyn.

The geological details have been especially elaborated for the Board of Water Supply from time to time by Professor W. O. Crosby, Dr. Charles P. Berkey and the writer. An extended account with many profiles has been prepared by Dr. Berkey and has been published as Bulletin 146 of the New York State Museum. under the title "The Geology of the New York City (Catskill) Aqueduct." While recording many important facts for the use of future geologists, the no less important object of the Bulletin has been to show the aid which geology can and did render engineering.

THE PROBLEM OF MIXED SULPHIDE ORES.

By W. R. INGALLS, New York.

(Annual Meeting, Quebec, 1911).

In considering the treatment of difficult zinc ores, it will help to clarify ideas if the history of this metal be briefly reviewed. The commercial production of zinc is scarcely more than 100 years old, at least in so far as European and American industry is concerned. There is some reason to believe that long before it was accomplished in Europe, the Chinese knew how to smelt zinc ores; but zinc has been an article of common commercial production in Europe for only a little more than 100 years. The production was scarcely 50 years old before attention began to be directed to the low-grade mixed sulphide ores; deposits of that kind occurring in Europe as well as in this country. The first proposal for the treatment of such ore, other than by distillation, was made by Rochel, about 1857. He proposed to roast sulphide ore so as to obtain zinc sulphate, leach out the zinc sulphate, and ultimately obtain zinc oxide. The process did not prove to be easy, and no record of its practical application is to be found, but the method of making zinc sulphate that has long been practised in the Harz is similar. For the next 40 years attention was directed especially to the hydrometallurgical treatment of zinc ores. During that time, the number of proposals has run into the hundreds; the number of individual patents has run into the thousands.

The majority have begun with the prescription to obtain a solution of zinc sulphate; then they proceed to tell how they are going to precipitate the zinc, etc. In fact, the obtaining of a solution of zinc sulphate is a difficult thing at the outset. The great majority of proposals of this character apparently have never been tried in the laboratory, much less in the works. It seems to be impossible—I shall not say that it is impossible, because in these days of discovery what seems impossible to-day may be possible to-morrow—but it seems to be impossible to convert zinc sulphide into the soluble sulphate by a roasting process without leaving so large a proportion of the sulphide undecomposed as to make the process uncommercial.

Baffled in that direction, the inventor naturally says: "Well, then, let us roast the ore to oxide, make sulphuric acid, and leach the oxide with the acid." This also looks simple on paper, but without going into any of the troubles accompanying the roasting of such ore, the extraction of zinc by such a lixiviation is in general far too low for commercial purposes. The reason for this was formerly a mystery, but we now know that in the roasting of a zinc ore containing iron there is formed a ferrite of zinc that is insoluble in acids. There is no difficulty about roasting a high-grade blende and dissolving the zinc with dilute sulphuric acid; but in the case of a highly ferruginous ore (which is one of the ores especially troublesome to treat) the extraction is likely to be as low as 60 per cent.

From the simple hydrometallurgical methods, inventors naturally turned to the subject of precipitation by electrolysis. It was found difficult, however, to obtain the right kind of a precipitation of zinc, but this difficulty might have been surmounted; in fact, was surmounted in some cases. Far more serious, however, was the condition that generally was left quite out of consideration, although it ought to have been the first subject of thought, viz., that all of the zinc salts absorb a large amount of energy in their formation, requiring the exertion of the same amount of energy for their decomposition; wherefore a little work with pencil and paper should have shown that the amount of power necessary for the electrolytic precipitation of zinc would preclude the likelihood of any useful development in that direction, except, perhaps, under extraordinary conditions. Those conditions may be generalized as the availability of unusually cheap power and the ability to make use of the anode reaction, as, for example, in the decomposition of a solution of zinc chloride, whereby zinc is precipitated at the cathode while chlorine is liberated at the anode, which chlorine may be utilized for the manufacture of bleaching powder. That, in fact, is done at the works of Brunner, Mond & Co., at Winnington, England, where electrolytic zinc has been produced, upon a relatively small scale, for a good many years. However, it must be recognized that the conditions at those works are exceptional.

There are other difficulties in addition to those already mentioned in connection with the hydrometallurgical and electrometallurgical methods of extraction. I shall not say that the hydrometallurgy of zinc has no future. It has, in fact, a certain commercial history, and it may have a future for the treatment of some ores under special conditions; but I feel safe in predicting that it will not become a branch of metallurgy of general application, and proposals in this direction are decidedly to be regarded askance. It is a source of wonderment that so much attention and so much money have been wasted upon this subject in the past. Large sums have been frittered away in taking out patents alone.

Along with the vast amount of experimentation in the field of hydrometallurgy, many attempts, dating back to an early time, have been made to smelt zinc ore in the blast furnace. This also has been a fruitless line of investigation. It is indeed possible to reduce and distil zinc in a blast furnace. That is essentially what is done in the Wetherill furnace, which has been used for a great many years for the manufacture of zinc oxide. From the Wetherill furnace, it is true, the residue of the ore remaining after expulsion of the zinc is not drawn off as a molten slag, which in the common conception of blast furnace smelting ought to be a result; but it is possible to drive off a large percentage of zinc from the top of a blast furnace and draw off molten matte and slag from the bottom, as, for example, in the Bartlett process formerly used at Cañon City, Colo., while the new Pape process, now successfully employed in Germany, is substantially another step in this direction. The fundamental difficulty in the blast furnace treatment of zinc ore is not in the smelting, but is rather in the condensation of the zinc as molten metal. Experience has shown the product invariably to be blue powder, zinc oxide, or a mixture of the two, Without attempting to go far into the reasons for this, I believe that they connect themselves primarily with the practical inability in a blast furnace to avoid the oxidizing effect of carbon dioxide.

Boudouard has shown that zinc oxide can be reduced by carbon monoxide only so long as the presence of carbon dioxide is very small, the permissible amount of the latter rising with the temperature. Thus, at 1000 deg. C. it must not more than 0.1 per cent.; at 1125 deg. not more than 0.2 per cent.; and at 1500 deg. not more than 0.76 per cent. With higher percentages at the respective temperatures, zinc is oxidized. It is difficult to see how in a blast furnace the percentage of carbon dioxide can be kept within those low limits. Even in the gasification of coal in the producer the percentage of unreduced carbon dioxide exceeds the figures above stated. In the ordinary retort the gas discharged, after the distillation is fairly in progress, is substantially pure carbon monoxide. It is possible to maintain that condition in smelting in retorts; other conditions imply relatively small retorts. These are the reasons why in the history of the art no one has been able to increase the size of the unit for zinc smelting. The number of retorts per furnace has been increased, but not the size of the retort itself. The classic case of the production of molten zinc in the blast furnace, the so-called Zinkstuhl of the Harz is undoubtedly to be ascribed to locally favorable conditions in the furnace, purely accidental.

Now, while all of this experimentation, interesting but more or less chimerical, was going on, some of it on a large scale, practical men were making progress in more simple ways. The zinc smelters by improvements in their art gradually became able to handle successfully ores of considerable impurity. High percentages of lead and iron ceased to have terrors. Silver and lead contents could be recovered either by smelting the entire residue from zinc distillation, or by subjecting it to mechanical concentration and smelting the concentrate. The choice between these alternatives depends simply upon commercial conditions. On the other hand, mill men made important improvements in their processes, enabling them to deliver to the smelter products that could easily be smelted. The experience in the United States is illustrative of this progress.

At Leadville, Colo., as far back as 25 years ago, we were treating mixed sulphide ores by jigging and tabling. We were able to treat profitably only those ores that were fairly high in lead, say 8 to 10 per cent. We had no market for our blende tailings, but foresaw that some day there would be a market, and saved them in a special dump instead of throwing them away; an early example of conservation. After we had exhausted the supply of ore of the above grade in lead we were no longer able to operate at a profit, and had to abandon the mill. The real beginning of the successful commercial treatment of these ores was a few years later, specifically in 1896, when the Wilfley table was introduced, inaugurating an era of concentration by fine grinding and tabling. Operators were then able to go back to the same deposits of ore that had been left five or six years previously, and were able to work profitably the low-grade material that had then been abandoned.

Soon after the introduction of the Wilfley table came the invention of the Wetherill magnetic machine, introduced first at Franklin, N.J., and later applied to the sulphide ores of the West. This machine was based upon a new principle in magnetic separation, viz., the use of magnets of condensed lines of force, giving magnetic fields of extraordinarily high intensity. Its success redirected attention to the older method of giving certain ores a magnetic roast, rendering them susceptible to magnetic machines of low intensity, which, previously, had not amounted to much for any purpose except the concentration of some kinds of iron ore. It was discovered that the chief previous difficulty was a failure to roast the ores in just the right way. The proper procedure having been learned, it became possible to separate the mixed ores of the Wisconsin field. A few years later we had also the invention of the Blake electrostatic separator, and a little later the flotation system was introduced at Broken Hill, New South Wales, at which place it has now displaced all other methods.

At the present time we have a rather wide range of special processes for the mechanical separation of minerals, processes that are not dependent upon specific gravity, which enable us to treat a great variety of ores. Thus from the mixture of blende and siderite, the latter may be rendered magnetic by a light calcination and then may be picked out by means of magnetic machines. Blende and marcasite may be separated by magnetic machines and by electrostatic machines. In Wisconsin both are working side by side. At Broken Hill, for the separation of blende and rhodonite, magnetic machines and flotation processes have both been used, the latter having proved the more profitable. Flotation has been applied to the separation of blende and fluorite in Kentucky, and experimentally for the separation of blende and barite. All of the minerals that I have mentioned are nearly alike in specific gravity and cannot readily be separated by methods depending upon difference in specific gravity.

While we can, however, treat in one way or another almost all kinds of mixed ores at the present time, there are some that are still particularly difficult. Such, for example, is the case of blende high in ferrous sulphide as a constituent of the blende itself. Blende sometimes contains as much as 20 per cent. iron. Given such a case it might be possible to effect an excellent concentration of the mineral, but the latter might still be too low in zinc to be a good marketable product. Obviously, in such a case, any kind of mechanical separation may be a failure. Another difficult ore is a crypto-crystalline mixture of sulphides, a mixture so intimate that no single mineral can be discerned by the naked eye. In such a case the primary difficulty is that no practicable degree of crushing liberates the constituent minerals. Another difficult ore is the excessively fine dissemination of blende in dolomite or limestone.

However, all of these difficult ores may be treated by a furnace method. Whether such will pay, or not, is dependent upon the grade of the ore and the economic conditions under which it occurs. The mixed ores of the Harz have long been smelted at Lautenthal in ordinary blast furnaces for the production of lead, the zinc being chiefly worked off in the slag, which is caused to run high in zinc. Very "zincy" slags have similarly been made in lead smelting at Broken Hill, at Marysville, British Columbia, and elsewhere. Recently, a company has been working the "zincy" slags of the Harz by the Pape process, obtaining zinc oxide by a modification of the Wetherill process, and subsequently distilling the zinc oxide for the production of spelter. A large tonnage of spelter has already been produced in that way. But while such a process may be conducted profitably under the conditions existing in Germany, it is hardly to be expected that a similar economic result could be obtained in British Columbia, where labor is relatively dear and where the mines are remote from the markets for the products. I have attempted to show that in one way or another practically all kinds of mixed sulphide ores can be treated metallurgically, but whether under given conditions it will pay to do so is a matter of an entirely different kind.

The question will naturally be asked, why, with this wide range of new processes for the treatment of mixed sulphide ores, has there not been a more extensive application in North America? The answer is, that although our mines have enormous quantities of zinc, that metal is chiefly scattered among mines that are relatively small, and after all we do not possess many big deposits of these ores. In fact, there does not seem to be in the Rocky Mountain region many really big zinc mines, except at Magdalena, Leadville and Butte. The biggest that we know of at the present time are apparently those at Butte. The ores there are of such a character as not to require any method of concentration other than simple gravity separation. In other cases the development of the mines is rarely sufficient to warrant the installation of plant of the nature necessary for the application of the special methods. So far as known, we have nowhere in North America any remaining deposits of mixed ores of such magnitude as those at Broken Hill. The mechanical methods of separation that I have mentioned are not very flexible, i.e., they are best adjusted to the conditions of a particular kind of ore and do not lend themselves well to the treatment of miscellaneous ores, varying widely in character from day to day. In other words, such processes are unsuitable for a custom works.

For those cases where it is desired to develop a market for miscellaneous ores, a place to which any miner can send and sell small outputs, or even an occasional lot of ore, it seems to be necessary to develop some system of pyrometallurgical concentration, or what may be roughly characterized as smelting. This idea is under consideration in some experimental work that is now being undertaken by the Department of Mines of the Dominion of Canada. In association with that work attention is also being directed to the subject of electrothermic smelting.

The possible treatment of zinc ores in the electric furnace is not a new idea. Attempts to smelt zinc ore in such a furnace have been made from time to time during the last 25 years. In fact, the Cowles brothers, who achieved distinction in connection with the aluminium industry, were engaged in an attempt to smelt zinc electrically before they directed their attention to aluminium. The list of proposals for the electrothermic smelting of zinc is almost as long as those for the blast furnace smelting of this metal and of those in the field of hydrometallurgy. At least two ambitious attempts at electric smelting upon a commercial scale have been made. Both were failures, not only commercially, but also metallurgically. I am disposed to think that such metallurgical difficulties as have been experienced in the electric smelting of zinc ores can be surmounted, but even with that assumption I am by no means prepared to assert at the present time, that electric smelting would have any advantage over standard methods. My present view of electric smelting, in so far as zinc is concerned, is that it is an unexplored field of metallurgy. In ploughing in this field something of value may be unearthed; but this the future can alone determine.

NOTES ON METAL LOSSES IN COPPER SLAGS.

By Thos. Kiddie, Vancouver, B.C.

(Western Branch Meeting, Vancouver, Feb., 1910.)

In the *Mining and Scientific Press* of November 13, 1909, Mr. J. Parke Channing, in a letter to Dr. R. W. Raymond, discusses the metal losses in copper slags. Mr. Channing refers to having discussed the subject with Mr. J. E. McAllister, General Manager of the British Columbia Copper Company, who "strongly held to the idea that the copper in the slag was in two forms, namely, one portion contained in occluded matte, and the other as an oxide." This discussion was started as a result of Mr. T. L. Wright's paper on the discrepancy between the ratio of copper to gold in mattes and in slags, in which Mr. Wright demonstrated that matte containing 50 oz. gold per ton of copper only showed a ratio of 12 oz. gold per ton of copper in the slag produced therefrom, and concluded that the difference in this ratio was caused by part of the copper contained in the slag being in the form of oxide probably not combined with gold, which would account for the difference in the proportions.

As bearing on this question, the writer would state that for some years past the amount of copper existing as oxide in ore slags has been somewhat regularly determined, i.e., whenever the copper slags would be above the average the copper existing as oxide and as sulphide was determined separately, in order to ascertain whether the increase in the copper content was due to improper settling of the slags or to oxidation, and as a result it was generally found that the increase in the copper was due to an increase in the amount of oxide and seldom as a result of an increase in the amount of copper as sulphide. The oxidized copper was determined by treating the slag with dilute sulphuric acid and estimating the dissolved CuO. electrolytically; then treating the residue with nitric acid and determining the amount of copper existing as sulphide.

Of course the copper soluble in dilute sulphuric acid may exist in two forms, as CuO. and Cu_2O. If the oxydized copper in the slags exists entirely as CuO, then the amount dissolved by sulphuric acid would represent its exact amount; while if it exists in the mixed condition, the copper soluble in dilute sulphuric acid would represent the total copper existing as CuO. plus one-half the amount of copper as Cu_2O, (as Cu_2O. is only partially decomposed by dilute sulphuric acid), according to the following equation:—$Cu_2O \text{ x } H_2SO_4 = CuO_4 \text{ x } Cu \text{ x } H_2O$. The writer has not determined the latter amount, as for practical purposes direct treatment with sulphuric acid was considered sufficient.

SLAG ANALYSES.

Illustrating the proportion of copper existing as oxide and sulphide, the following results are submitted:—

Total Copper per cent.		Copper as CuO per cent.	Copper as Cu_2S per cent.
Sample A	0.455	0.300=65.934% of total.	0.155=34.06 % of total.
Sample B	0.220	0.120=54.545% " "	0.10 =45.454% " "
Sample C	0.075	0.015=20.00 % " "	0.06 =80.0 % " "

It will be observed that in the 0.075 copper slag only 20 per cent. of the total copper exists as oxidized copper. In the 0.22 slag, which is a typical slag, 54½ per cent. of the copper exists in the oxidized condition, while in the 0.45 slag practically 66 per cent. exists in the oxidized condition. In other words, a slag carrying, say, one-half of one per cent. copper will contain practically two-thirds of its copper as oxide and one-third as sulphide, and the increase of copper is usually due to excessive oxidation rather than to imperfect smelting.

In order to obtain the same ratio between the gold and copper in matte and the slag therefrom, it would appear that we must consider only the copper existing as sulphide as being combined with gold, so that instead of a gold-to-copper ratio of 5.27 oz. gold per ton of copper in slag A, we would have 15.48 oz. gold per ton, and in sample C, instead of a gold-to-copper ratio of 10.90 oz. gold per ton of copper, we would have 24 oz. gold per ton, which would more nearly approximate the ratio of copper to gold in the matte.

These results, proving the existence of copper in an oxidized condition in copper slags, fully confirm Mr. L. T. Wright, who in the *Mining and Scientific Press* of November 27, 1909, states his "belief that some of the copper of the slag may have been existent as silicate."

The subject naturally recalls the question whether more than one settler is required in order to obtain the cleanest slags, and this question can only be intelligently determined by an examination of the slags along the line indicated. If the proportion of copper existing in the slag as sulphide is high, say 66 per cent. of the total, then it would appear that a second settler would be advantageous, If, on the other hand, it were found that 66 per cent. of the copper existed in the oxidized condition, then additional settling capacity as such would be unnecessary. Other means of reducing the copper of the slag should be devised, and one of the most simple and effective means of accomplishing this, without the expense of maintaining a separate furnace for the purpose, is by running the slag over or into a bath of matte in a second settler, when reduction of the copper oxide by low grade matte is effected, the FeS of the matte acting as the reducing agent on the oxide of copper, which is proved by the increased grade of the matte tapped from the second settler compared with that of the first. In order to keep this second settler open it was found necessary to use a settler not water-jacketed so as to prevent loss of heat by radiation, etc.

These results were further confirmed by mixing the shotted slag A with 3 per cent. of pure FeS and melting in a clay crucible, allowing it to cool, the products being a low grade copper matte and a slag containing only 0.05 per cent. total copper.

A STUDY OF THE COMPARATIVE EFFICIENCIES OF CERTAIN METHODS OF SCREENING AND CLASSIFYING FINE MATERIAL

AND

A COMPARISON OF SCREENED WITH CLASSIFIED FEED ON THE WILFLEY TABLE.

By J. R. Cox, M.Sc.; G. G. Gibbins, M.Sc., and J. B. Porter, D.Sc.

Introduction.

For fifty years and more it has been recognized that the operations of ore dressing depend on certain fundamental principles, of what used to be called the Natural and Mathematical Sciences; and from the days of Goetzschmann and Rittinger down, a succession of able and learned scientists have devoted themselves to the study of concentration; but until recently these men have been few and have usually held official or professorial positions, and the actual design and superintendence of plants have, with a few notable exceptions, been left to so-called practical men.

The natural result of the conditions above mentioned was that the development of the technology of concentration was erratic and on the whole slower than in those branches of engineering when scientific management was more obviously necessary and therefore sooner employed. New methods were, of course, developed and many novel and effective pieces of apparatus were invented; but in too many cases these were used only near their place of origin, and not always wisely even then, and in general the art of concentration suffered from what might be called provincialism, each district having certain favourite processes and machines and contentedly remaining either ignorant of or indifferent to the practice of other places.

Within the last few years there has been a marked change, and now it is generally recognized that ore-dressing establishments need highly educated works-managers, quite as much as smelters or mines. The number of plants directly superintended by such men is probably ten times as great as it was ten years ago and the inevitable result of this change has already shown itself in a revival of interest in ore dressing and the rapid and widespread introduction of new and improved apparatus and methods. Significant also of this change is the very much more general interest that is being shown in researches bearing on ore-dressing work and in the more intelligent use that is being made of modern scientific methods in studying and interpreting ore-dressing operations.

The first function of a university is, of course, to fit its undergraduates for their future life work, but a second and scarcely less important duty is to carry out studies of an advanced theoretical character, and when any department of a university possesses technological laboratories these studies should be directed not merely to the purely theoretical side of the subject but also and often most profitably to a careful investigation of existing methods and apparatus with a view to determining their limitations. It is the privilege of the senior author of this paper to direct such a laboratory, and thus each year in addition to his teaching work to initiate series of experiments bearing on some of the many unsolved problems of ore concentration.

One practical question which has never been solved to the satisfaction of the profession is the determination of the most effective method of preparing fine material for table concentration. Jigs are seldom commercially satisfactory for material finer than ten or, at best twenty, mesh, and as no table can treat the mixed pulp and slime below this size without large losses, it has for years been customary to classify this pulp more or less accurately in rising current apparatus or settling boxes, and to feed the roughly graded stuff to two or more tables or series of tables each suitably adjusted for its class of pulp.

This method has had the merit of cheapness and, so long as plain tables such as the Evans buddle were used, this pulp, if reasonably thickened, has been theoretically at least more suitable for concentration than sieved material. Unfortunately, however, classifiers as ordinarily built and operated in mill work are very imperfect machines and give only a very approximate grading at best, whereas screens although costing more to operate are commonly supposed to do much more accurate work; and it has always been a moot point as to where the reliable sieve should give place to the "unreliable" classsifier in preparing pulp for concentration.

The problem has been made at once more difficult and more important by the comparatively recent invention and general introduction of two very important types of machines,—namely—riffled jerking tables like the Wilfley, and fine wet screens such as the Callow belt. The latter and equivalent devices such as impact and vibration screens have greatly cheapened fine screening, thus making it commercially practicable in many cases to size down to 60 mesh or even finer before beginning to classify, and the jerking motion of the Wilfley table has lessened and perhaps completely reversed the advantages of classified as compared with sized feed.

The problem of determining whether to screen or classify Wilfley feed is thus seen to be of both theoretical and of practical importance and is therefore particularly interesting to the experimenter. Prof. Richards has already worked on it and his results as published* are extremely interesting, but as they seemed to the authors somewhat unconvincing it was decided to carry out a series of tests on a somewhat larger scale in the McGill ore dressing laboratory.

The main purpose of the investigation was to determine if possible the comparative merits of sized, classified and deslimed feed for Wilfley table work; but it was determined to use a genuine ore and a somewhat difficult one rather than an artificial mixture of two pure minerals as in Prof. Richards' experiments and it was also decided to work under conditions approaching the practical as nearly as possible.

The work thus resolved itself into

(1) A determination of the efficiency—i.e. perfection of operation—of the Callow screen under standard conditions.

*Transactions—American Institute of Mining Engineers, vol. xxxviii, pp. 556-580, and xxxix, pp. 303-315.

(2) A determination of the efficiency of some good type of classifier.

(3) The preparation of sufficient quantities of properly screened and classified ore and the exact determination of their characteristics.

(4) The design of a feeder capable of supplying pulp at a constant rate.

(5) The concentration of the several lots of prepared ore on the Wilfley table.

(6) The assaying of the products of the several tests, and the interpretation of the results.

The senior author is responsible for the initation of the investigation, and for the general scheme followed; but other duties prevented him from giving attention to the work as it progressed, and to the junior authors (both research scholars in the Mining Department of the McGill University and members of the graduate school) is due the whole credit for carrying out a very laborious and painstaking investigation.

The division of the work between the investigators was as follows: Mr. Cox undertook the study of the Callow screen; Mr. Gibbins that of the Bell classifier, and both worked on the actual trials of the sized and classified pulp on the Wilfley table. A similar division was followed in the preparation of this paper. Messrs. Cox and Gibbins, although they consulted one another freely, prepared separate reports on their respective sections of the work, and these reports have been used as far as possible in their original form by Dr. Porter in the preparation of this paper.

In closing this introduction, the authors wish to express their appreciation of the great value of the assistance they received from Mr. J. W. Bell, Assistant Professor of Mining in McGill University. They also wish to thank Mr. Chas. Landy and the members of the laboratory staff for very material aid.

PART I.

AN INVESTIGATION OF THE EFFICIENCY OF FINE SCREENING DEVICES, WITH PARTICULAR REFERENCE TO THE CALLOW REVOLVING BELT SCREEN.

Until recent years very little screening was done of material finer than about 1 mm., except in connection with stamp milling and other operations not strictly to be considered as concentration. For sizes larger than this, but not too coarse, some form of revolving trommel is most commonly used; but it has not been found economical to employ this type of screen for fine material, on account of the expense of the frequent renewal of the large screen areas employed, and the very low output consequent upon the blinding of the screens. Material finer than 1 mm. was therefore generally treated in some form of hydraulic classifier or system of settling tanks. This method is, however, open to the objection that as ordinarily used at least the classifier is a less exact and therefore a less reliable machine than a screen; hence many attempts have been made to evolve a screening machine which would economically take the place of classifiers.

In the quest for a good fine screening machine five general types seem to have been evolved:

(1) Screens fixed in a cylindrical or conical frame, the whole revolving upon an axis usually inclined.

(2) Shaking screens:

(*a*) Horizontal
(*b*) inclined } which may have (*a*) horizontal
(*b*) vertical } non-cond.

(3) Vibrating screens, inclined.

(4) Screens of the belt type.

(5) Conical screens having the feed projected upon the screen surface with some force.

Very little printed information of value is to be found as to the work of these screens. Types (2) and (3) do good work and with the exception of (2*a*) are free from blinding, but expensive in upkeep. Types (1) and (5) do not wear out so quickly, but are more apt to blind.

The fourth type does moderately good work, is almost absolutely free from blinding, and has a large capacity. The Callow screen is of this type, and the following tests were all carried out on this screen. The machine used was a standard design single 12″ belt machine made by Fraser & Chalmers, Ltd., of London, England, under the Callow patents. The screen belts were made for Fraser & Chalmers by Greenings of Warrington, and were of Institution of Mining and Metallurgy standard mesh. The machine consists of an endless belt of screen cloth (about eight feet in circuit and one foot wide) edged by rubber lips which prevent the sands from spilling off the screen, and take the strain of driving off the cloth. This belt is carried on two overhung horizontal rollers one foot in diameter and travels at from 30 to 120 feet per minute as desired. The sands are distributed across the width of the belt by a slightly sloping feed sole, and fall in the direction of travel of the belt. A shaking spray near the centre of the belt helps to put the undersize through. The oversize is washed off the surface of the belt by another spray as it passes over the tail roller. This machine should have a capacity of rather less than a quarter that of the standard Callow screen, which has two belts each two feet wide and slightly longer than this one.

OUTLINE OF TESTS CARRIED OUT.

Two series of tests were made: one upon barren sands for the purpose of testing the capacity and efficiency of the screen, and one to prepare ore for the Wilfley table trials.

For the first series a considerable quantity of a pure hard nepheline syenite was obtained from the Forsyth quarries at the back of Mount Royal. This was broken in a Comet crusher to a maximum size of about 1 inch and then fed to a 3′ Huntingdon mill having an 18′ discharge screen.

The pulp from the mill before going to the Callow screen was elevated by a centrifugal pump to a small desliming cone which took out the major portion of the slimes. A screen analysis of the remaining sands showed the following distribution of sizes:*

	Mesh.	% Weight.
On..................	20	7.0
"	30	17.2
"	40	8.9
"	60	12.4
"	80	15.2
"	100	3.2
Through............	100	37.1
		100.0

* The writer believes that in any system where crushed material is treated on screens, or even in classifiers, it is the better practice first to remove most of the slimes. No screen or classifier can be expected to do good work on a feed crowded with slimes.

The Callow screen, Plate I, was fed from a 36″-60° cone capable of holding about 500 lbs. of pulp, which was sent up into the cone by means of a small hydraulic elevator, the surplus water overflowing from the lip of the cone and carrying a small amount of slime with it. The water necessary to operate this elevator amounted to about 18 gallons per minute. This water was fed continuously throughout the test, thus ensuring a constant height of head, although at the beginning of the test this head would be chiefly of pulp and of high specific gravity, while at the end there would be but a little pulp in the bottom of the cone with water above. Unfortunately this method of feeding involved a certain amount of classification and the feed at the beginning of each coneful was generally somewhat coarser than near the end, and the very end of a coneful of sand was always marked by a rush of fines, which unless guarded against, had a noticeable effect upon the run.

The bottom of the cone was provided with a series of interchangeable circular orifices held by grooved side pieces. These orifices varied from ¼″ up to ¾″ in diameter, the difference between the size being 1-16″. So long as the size of the pulp and the head of water in the cone was kept the same, the rate of feed from any one orifice remained practically constant.

So long as any pulp remained in the cone, the rate of feed and the amount of water in the feed stream were remarkably constant at about 35%, and were irrespective of the size of the pulp. Any additional water to bring the ratio of water to feed, up to the required figure, was added from a calibrated cock at the head of the feed sole.

The screen analysis of the sands (p. 5) showed that a 60-mesh screen doing perfect work would pretty evenly divide the feed—there being 55.5% of the sands through 60 mesh. Hence, a 60 mesh screen was used for the first six runs and the rate of feed, belt speed, and water varied.

Table 1 gives the results of these runs.

Table 2 gives the results of the runs on ore subsequently used for the Wilfley table.

The "capacity" of a screen is the output of material which it will treat in a given period of time, and is irrespective of whether the screening be well or ill done—that is to say, whether the oversize is well or ill, freed from fine material which should have passed through.

The capacities as given by the manufacturers' catalogue for Callow screen are as follows, assuming a 1:1 feed:

Mesh	Tons–24 hrs. Standard size	Tons–24 hrs. Small size	lbs.–min. Small size
20	250	62.5	87.0
30	200	50.00	69.5
40	150	37.5	52.2
60	125	31.2	43.3
100	75	18.7	26.0

It will be noticed that throughout the tests the capacities obtained averaged about one-third of these amounts. The writer is of the opinion that both this and the somewhat low efficiencies obtained may be traced to the fact that in all cases the screen cloth used conformed to the standards recently recommended by the Institution of Mining and Metallurgy—that is, the wire used in making the screens is the same size as the space between the wires, so that the percentage of opening is only 25%, whereas the screens ordinarily in use may have a percentage of opening as high as 45% with a proportionately larger increase in capacity.

The "efficiency" of a screen has been taken as the quantity of undersized material passed through the screen, expressed as a percentage of the amount of undersized material in the screen feed. Thus a screen which left no undersize material in the oversize, would have 100% efficiency. The efficiency in this sense is, therefore, irrespective of capacity, and it is conceivable that a machine might have almost perfect efficiency, and still be so low a capacity as to be commercially worthless. The true worth of a screen is, therefore, a function of the capacity and efficiency in the sense in which these words are here used.

The factors which affect this efficiency are:—

(1) The thickness of the bed of sands on the screen.

(2) The time this bed is allowed to remain upon the screen.

(3) The ratio of the quantities of oversize to undersize.

(4) The proportion of oversize material which is nearly but not quite small enough to pass through into the undersize.

(5) The amount of water in the pulp (if wet screening is employed).

(6) The percentage of opening of the screen employed.

With regard to (1) and (2) it is obvious that the thinner the bed the quicker the screening will be done, and the greater will be the efficiency, but the smaller the capacity.

A consideration of (3) illustrates the weakness already referred to in the use of the above definition of efficiency as a means of judging the usefulness of the work done by the screen. Take for instance two lots of sand of say 100 lb. each and assume that screens analyses show that lot 1 has 20% and lot 2, has 60% of particles below a certain screen size, say 60 mesh. These lots are then screened on the same 60-mesh screen under conditions such that the efficiency is the same—say 75% in both cases. The undersize remaining in the oversize after the screening will in the case of lot 1, amount to (20 — $\frac{75}{100}$ of 20) = 5 lbs. or 5.88% of the "oversize" produced. In the case of lot 2, it will be (60 — $\frac{75}{100}$ of 60) = 15 lbs. or 27.3%. In each case the efficiency is the same, yet there is a difference of over 20% in the percentage of undersize left in the "oversize," a fact which must be borne in mind when comparing the work of different screens.

With reference to (4), it is obvious that grains which will just fail to pass through a screen are much more likely to blind it and thus reduce its capacity than coarser material, and in this connection it might be remarked that some types of screens become blinded more readily than others and, therefore, are particularly ill-suited for material of this character.

Both theoretical consideration and practical experiment seem to show (5) that up to the point when a screen begins to get flooded it will do more and better work the more water is used.

The best screening (6) will naturally be done with wire cloth, having a large per cent. of opening, i.e., made of fine wire; but such screens wear out quickly and their meshes are also likely to become deformed. On the other hand it is possible that the standard of 25% opening, adopted by the Institute of Mining and Metallurgy, may give a needlessly substantial screen in the coarser sizes, and that for commercial purposes cloth made of finer wire, but with the same clear openings, may be more economical.

TABLE 1.—CALLOW SCREEN TESTS.

(Mount Royal Syenite).

Test No.	Mesh of screen used	Under-size in feed % of feed	Wt. over-size lbs.	Wt. under size lbs.	Under-Size left in over-size % of overs	Effi-ciency %	Orifice	Rate of feed lbs.-min.	Belt speed ft. per min.	Ratio water / dry feed
Sy. 1	60	55.5	100.0	35.0	40.0	46.7	7/16″	17.5	90	3.6
Sy. 2	60	36.4	126.0	44.0	14.1	71.2	7/16″	15.9	86	3.8
Sy. 3	60	40.2	110.0	43.0	16.9	69.9	7/16″	15.4	86	5.4
Sy. 4	60	39.8	69.0	30.0	13.6	76.2	7/16″	14.3	86	7.2
Sy. 5	60	21.4	135.0	21.5	8.8	64.5	5/8″	31.3	86	3.5
Sy. 6	60	42.4	124.5	52.2	18.2	69.7	3/8″	11.8	86	4.1
Sy. 7	100	35.3	105.0	23.0	13.6	61.5	3/8″	10.7	100	4.9

TABLE 2.—CALLOW SCREEN TESTS.

(Bruce Mines Ore.)

Test No.	Mesh of screen used	Under size in feed % of feed	Wt. over-size lbs.	Wt. under-size lbs.	Under size left in over-size % of overs	Effi-ciency %	Orifice	Rate of feed lbs.-min.	Belt speed ft. per min.	Ratio water / dry feed
Cu. 1*a*	100	13.1	58.5	4.4	7.0	51.7	3/8″	18.0	100	3.2
Cu. 1 *b*	100	5.2	92.0	3.4	1.7	67.7	5/16″	9.4	100	5.9
Cu. 1	100	13.9	1659.0	183.0	4.4	71.4	5/16″	9.0	100	5.9
Cu. 2	60	20.2	1462.0	181.0	10.3	54.5	7/16″ & 3/8″	17.7	90	3.8
Cu. 3 *a*	40	34.4	253.0	42.0	23.5	41.6	1/2″	26.8	80	2.8
Cu. 3	40	28.8	1175.0	243.0	14.0	59.6	7/16″	22.1	80	2.9
Cu. 4 *a*	30	42.1	131.0	32.8	27.7	47.4	1/2″	32.0	80–110	2.4
Cu. 4	30	39.8	911.0	252.0	23.2	54.3	7/16″	23.4	80	3.3
Cu. 5 *a*	20	73.4	112.0	51.8	61.1	43.2	1/2″	32.0	65	2.4
Cu. 5 *b*	20	76.9	99.0	61.8	62.5	50.0	1/2″	32.0	95	2.7
Cu. 5	20	74.5	435.0	326.0	55.6	57.4	7/16″	23.0	80	3.1

Runs followed by a letter, e.g., Cu. 1 *a*, *b*, etc., were tests as a guide to determining the best working conditions for each screen. The products of these test runs were mixed and added to the feed for the main run.

Commenting upon the runs individually it will be noticed that the efficiency of Sy. 1, Table 1, is only 46·7%. This is in part due to the larger proportion of fines in the feed (55·5%) and in part to a rush of fines at the end of the run, some of which in consequence got carried over into the oversize. In the rest of the tests in Table I the run was always stopped before the sand in the feed cone got too low.

Tests Sy. 2, 3 and 4 show the influence of varying the ratio of feed water to feed. With a ratio of 3·8 we got an efficiency of 71·2 %. By almost doubling this ratio (90% to 7·8,) we get an increase of efficiency of only 7% to 76·2% (5% absolute), with lower capacity.

In Sy. 5 the rate of feed was doubled with a decrease in efficiency of only 6·7 from Sy. 2. It will be noted, however, that the per cent. of fines in the feed was much less—21·4 instead of 36·4 in Sy. 2.

In Sy. 6 the reduction of the feed to only 11·8 lbs. per min. failed to give a very good efficiency.

Sy. 7 was run to get an idea of the working of the No. 100 screen before starting to prepare the copper ore for the Wilfley Table.

Table 2 shows the results of the runs on this copper ore. With the exception of Cu. 1 the efficiencies are lower than in Table 1, chiefly on account of the large amounts of undersize in the respective feeds, especially in the coarser sizes. Furthermore, the runs reported in this table had to be carried to the very end of the feed, with the consequent rush of fines at the end.

It will be noticed that the ratio of water to feed is largest with the fine screens and smallest for the coarse screens. It was found to be impossible to keep the ratio much higher than 3: 1 with the coarse screens without flooding them.

Runs Cu. 5 (a) and (b) show the effect of varying the speed of the belt. The increase of speed from 65 to 95 feet per min. thus giving a thinner bed of pulp upon the screen, increases the efficiency from 43·2 to 50·0%. It would seem advisable, therefore, to use only high speeds, but it has been found in practice that high speeds wear out the belts too quickly, because of the greater strain on the cloth and the rapid bending and unbending of the mesh as it passes over the rollers. It is a great deal owing to this bending of the mesh, that the Callow Screen is so free from blinding. Any grains that may have stuck in the openings are loosened by the bending of the cloth and are at once washed off by the cleansing spray opposite the end of the roller.

The feed sole, which is fan shaped, gives a very even distribution of the feed over the belt, and during the course of the two-inch drop from the lip of the feed sole to the surface of the screen a certain amount of separation takes place between the large and small grains which help the screening action very considerably. The large grains, owing to their greater momentum, have a slightly flatter trajectory on leaving the lip of the feed sole than have the smaller grains; consequently the large grains strike the screen a little in front of the small grains.

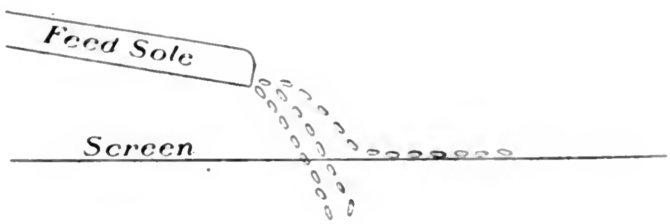
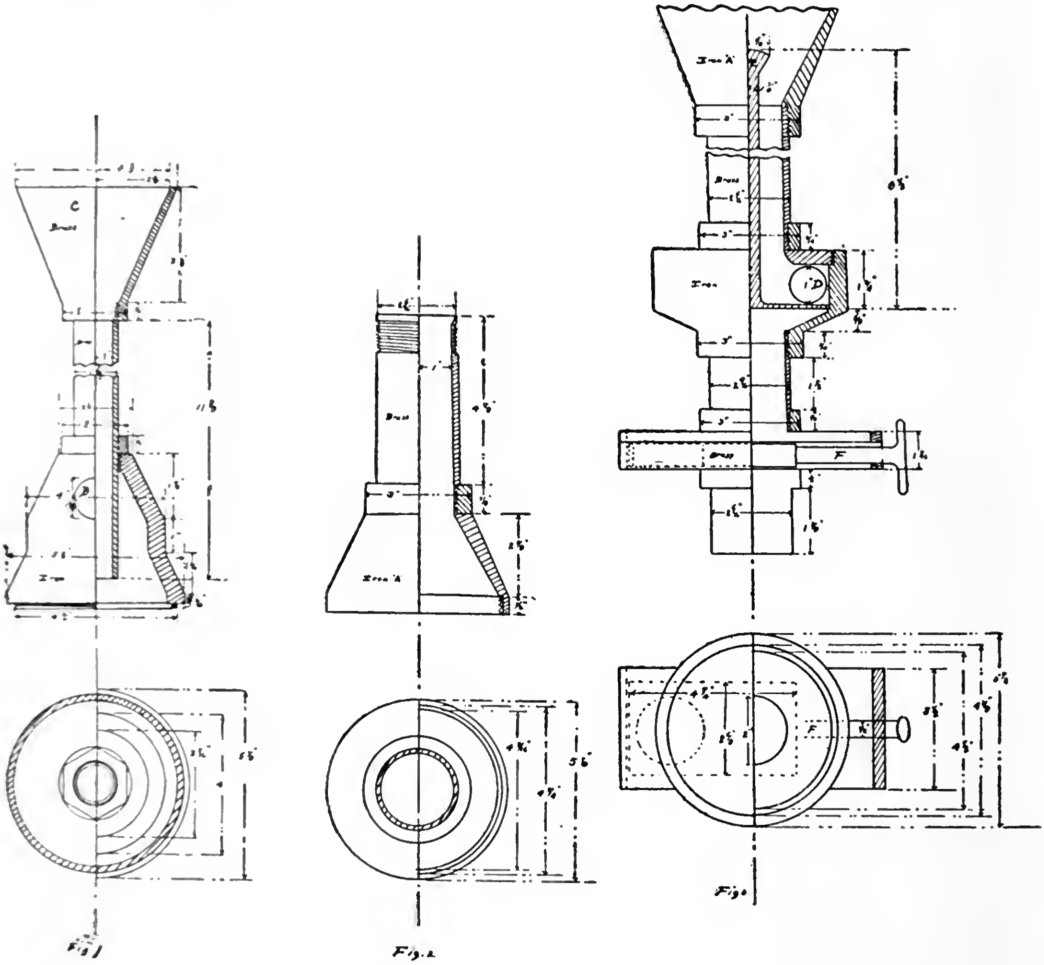


FIG. I.

These latter, unhindered by large grains, immediately pass through the screen. This idea is borne out by the fact that the screening action is practically completed in the first inch after the feed stream strikes the screen. The shaking spray seems to put through very little undersize, although it no doubt forces through some grains or loosens up others which have caught in the mesh.

In general the Callow screen may be said to show reasonable efficiency and large capacity. Screen cloth of the Institute of Mines and Metallurgy standards may not, however, prove economical to use with screening machines of this type for reasons already given and the belt speed should be as high as is possible without excessive screen renewals. It is also very desirable to use some form of de-watering device before screening in most cases.



DETAILS OF THE BELL CLASSIFIER.

EXPLANATION.

"C" is the feed funnel.

"B" is the discharge or overlaying pipe.

"D" is the hydraulic water supply pipe.

Fig. 1—Classifier. Fig. 3, shows the classifier complete.

Fig. 2—A merely and detailed drawing of the counterpart of the classifying chamber, showing Fig. 1 and corresponds to the first part of Fig. 3 as indicated.

"E", Fig. 3, shows the plug which scatters the feed.

The hydraulic water entering at P at right angles to the feed causes a swirl and effects a better separation of the material.

"G" shows the base plug which enables the spigot product to be drawn off without altering the water supply.

PLATE I

Callow Screens and Wilfley Tables with Cone feeders, Sampling devices, etc.
Ore Dressing Laboratories, McGill University

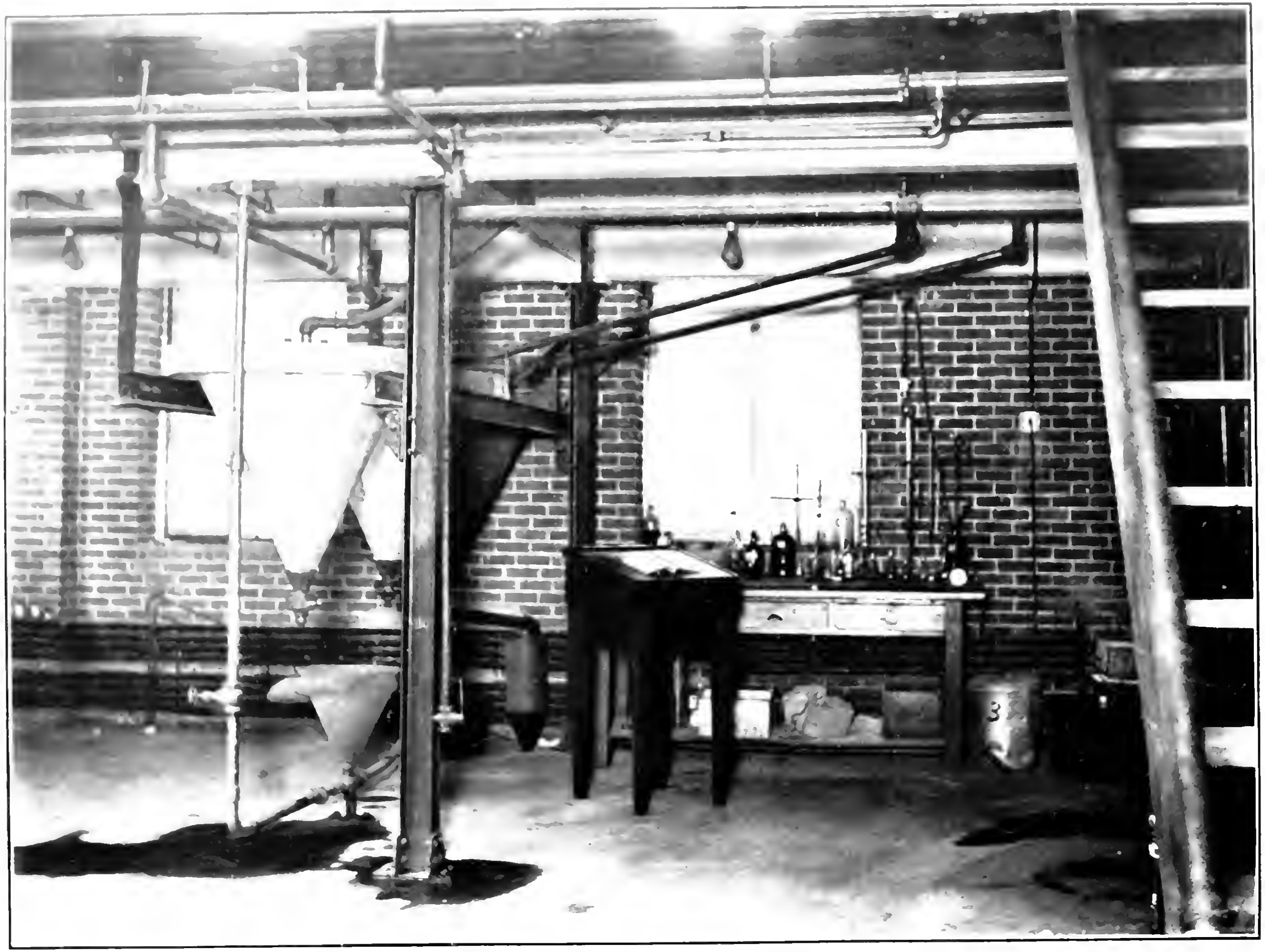


PLATE II.

Settling and Feeding Cones, Hydraulic Elevator, etc. Ore Dressing Laboratories, McGill University.

PART II.

AN INVESTIGATION OF THE EFFICIENCY OF CLASSIFYING APPARATUS AND ESPECIALLY OF THE BELL CLASSIFIER.

Preparatory Classification Tests with Syenite

As there was only a limited supply of the ore on hand, it was decided to run the preliminary tests on syenite. This rock was crushed in the comet gyratory crusher to about one-half inch, and sent directly to the stamp battery where it was crushed to eighteen mesh—the crushed product being deslimed by means of a desliming cone.

The average rate of crushing in the stamps was 12·5 lbs. per minute or 5·4 tons per 24 hours, giving a duty per stamp per 24 hours of 1·08 tons. The weight of the stamps was 600 lbs.; drop, about 6 inches; water, 12 gallons per minute.

An approximate screen analysis of the sands resulted as follows:—

TABLE 3.

Weight of screen sample.......	557	grns.		
" on 20 mesh...........	54	"	or	9·75%
" " 30 "	107	"	"	19·31%
" " 40 "	41	"	"	7·40%
" " 60 "	58	"	"	10·46%
" " 100 "	96	"	"	17·33%
" " 150 "	66	"	"	11·91%
" " 200 "	72	"	"	13·00%
" through 200 mesh.......	60	"	"	10·82%
Total....................	554	"	"	99·98%

It should be noted that the standard screens of the Institute of Mining and Metallurgy were not used in the screen analyses of the preliminary runs. All screening was done by hand.

The above analysis shows a concentration on the 30 mesh and on 100 mesh, but otherwise the products are fairly well divided.

All the classification was done in a classifier designed by Mr. Bell and made in the machine shop of the laboratory. The details of the main parts of the classifier are shown in the accompanying drawings, and the photographs give the general arrangement of the feeding cone, overflow cone and classifier.

The ore was dumped into the lower or overflow cone and forced by water pressure ejector up to the feed cone. Both cones were fitted with a device for preventing the classification action of the pump from having a serious effect on the feed. This device consisted in a small cone placed directly in the centre of the large cone near the bottom and held in place by four bars bolted to the cone. The fine material tends to settle along the sides of the cone and hence in emptying the cone the coarse sands come out first. The action of the inner cone causes a considerable mixing of the ore, because the coarse ore is caught by the small cone and forced to the sides and hence the fine material is drawn down with it. Further observation has revealed the fact that if the inner cone had been double the results would have been much more perfect. With the single cone (Fig. 2), a sort of vacuum is formed at "a" and the coarse material rushes in to fill

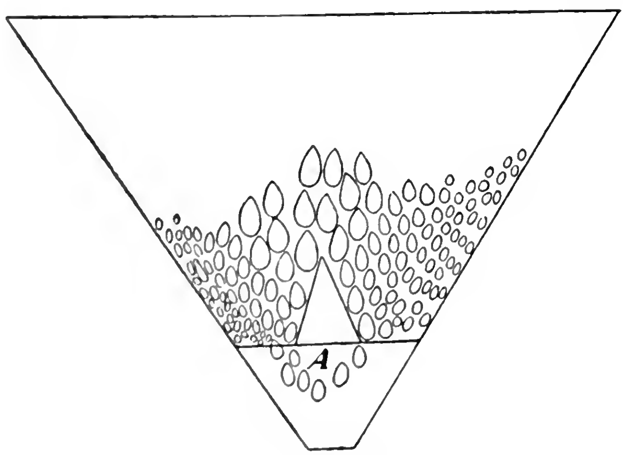


FIG. 2.

this, whereas when a double cone is used, (Fig. 3), the material is drawn along two passages "b" and "c" and a much better mixing results. The orifice at the bottom of the cone is one inch in diameter. By means of grooved slides corresponding orifices of smaller size can be used and any desired feed secured.

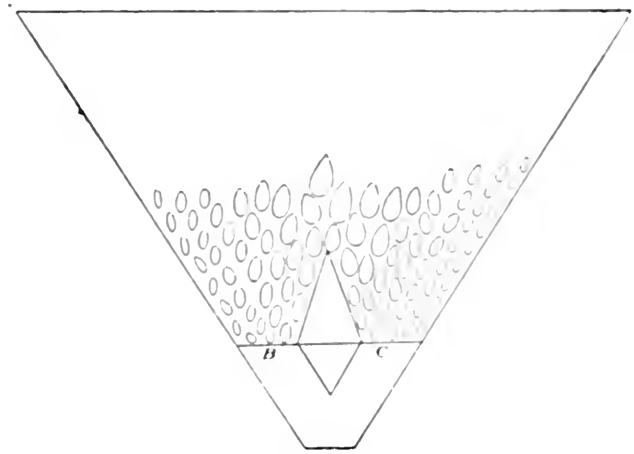


FIG. 3.

A set of these feed-orifices from a plug up to one inch is provided, each succeeding orifice being 1-16″ in diameter larger than the preceding one.

The classifier proper is provided with a glass plate in front and an electric light on the inside. This device enables one to see the movement of the pulp. By means of the sliding stop-cocks (see drawings of classifier details) the spigot can be emptied without changing the hydraulic water. Pressure water is provided to clean out the spigot. Altogether this classifier gave very satisfactory results.

A trial run on the syenite was made with a feed opening of 5-16″, and about 0·4 gallons of hydraulic water per minute. A screen analysis of the over-product follows:—

(It should be noted that in all the tests a constant head of water was maintained in the feed cone.)

TABLE 4.

Weight of screen sample . .	200 gms.		
" on 20 mesh.	1 "	or	0·5 %
" " 30 "	3 "	"	1·5 %
" " 40 "	3 "	"	1·5 %
" " 60 " . .	8 "	"	4·0 %
" " 100 "	36 "	"	18·0 %
" " 150 " .	41 "	"	20·5 %
" " 200 "	46 "	"	23·0 %
" through 200 mesh.......	61 "	"	30·5 %
Total.....................	199		99.5 %

From the above figures we see that 7·5 % is coarser than 60 mesh. The amount of hydraulic water was very small—just a mere trickle, so that it would appear that the feed was too fast; accordingly a $\frac{1}{4}''$ orifice was used in the tests proper.

It was decided to take about 300 lbs. of the rock and to start with a low hydraulic current, gradually increasing it, thus making the overflow the finished product in each run. Four such classifications were made, giving five sizes.

The results of the tests were as follows:—

TABLE 5.

Test No.	Hydraulic water in galls. per min.	Feed rate, wet–lbs. per min.	Do. dry	Feed water	Total water	Time of run, in min.	Weight of Prodt.	Act. Feed per min.
C_1 ...	0.30	7.36	4.86	0.25	0.55	52½	66	5.57
C_2 ...	1.10	12.00	7.24	0.48	1.58	34	99	6.67
C_3 ...	1.55	13.88	7.36	0.65	2.20	18½	70	6.92
C_4 ...	2.02	14.24	6.94	0.73	2.75	08	34	7.25
C_4 spig ot	......	......	......	......	......	......	24	
							293	

It was found that a hydraulic current of 3.84 gallons per minute was required to force over the largest grains.

It is interesting to note the continual increase of the feed water and with it the actual feed rate as given by the extreme right hand column.

The true feed rate agrees very well with the rate given by the minute sample. The increased amount of the feed water is due to the increased coarseness of the feed and the consequent greater space between the rock particles. This also causes the feed rate to increase because, as the fines get taken out, there is less opposition to the flow of the grains down the side of the cone, among other grains and through the orifice.

It was hoped when the quantities of hydraulic water were decided upon to produce five classes more or less equal in weight, but it will be noticed that the results leave much to be desired in this respect, test no. C_2, in particular, producing considerably more than a third of the total feed instead of one-fifth.

Screen analyses were made of all the products in order to find out the efficiency of the classification.

PLATE III

Bell Classifier—with cone feed—Hydraulic Elevator, Settling boxes, etc., set up for test.

Ore Dressing Laboratory, McGill University.

PLATE [illegible]

[illegible] for crushing small samples.
[illegible] Laboratories, McGill University.

These tests resulted as follow:—

TABLE 6.

TEST No. C_1. / TEST No. C_2.

Mesh	Weight in gms. (C_1)	% (C_1)	Total weight (C_1)	Weight in gms. (C_2)	% (C_2)	Total weights (C_2)
	417	100.0	66 lbs.	595	100.0	99 lbs.
On 20	few grains	....	....	2.0	0.3	0.3
30				16.0	2.7	2.7
40 (30, 40, 60 together for C_1)	1.8	0.4	0.3	22.0	3.7	3.7
60				76.0	12.9	12.8
100	13.0	1.4	2.0	238.0	40.3	39.9
150	79.0	20.7	12.5	138.0	13.4	23.2
200	176.0	42.4	28.0	72.0	12.2	12.1
Thr. 200	146.0	35.2	23.2	27.0	4.6	4.5
Totals - -	415.8	100.1	66.0	591.0	100.1	99.2

TEST No. C_3. / TEST No. C_4.

Mesh	Weight in gms. (C_3)	% (C_3)	Total weights in lbs. (C_3)	Weight in gms. (C_4)	% (C_4)	Total weights in lbs. (C_4)
	200	100.0	70.0	225.0	100.0	34.0
On 20	15.0	7.5	5.2	43.0	19.2	6.5
30	59.0	29.5	20.7	111.0	49.5	16.9
40	36.0	18.0	12.6	33.0	14.7	5.0
60	44.0	23.0	15.4	26.0	11.6	4.0
100	37.0	18.5	13.0	10.0	4.4	1.5
150	7.0	3.5	2.5	0.5	....	
200	1.5	0.8	0.5	....	0.4	0.1
Thr. 200	0.5	0.2	0.2	0.5	....	
Totals - -	200.0	100.0	70.1	224.0	99.8	34.0

TEST No. C_4.—SPIGOT.

Mesh	Weight in gms.	%	Total weights in lbs.
	284.0	100.0	24.0
On 20..........	126.0	44.4	10.7
30..........	126.0	44.4	10.7
40..........	21.0	7.4	1.8
60..........	8.0	2.9	0.7
100..........	2.0	0.7	0.2
150, 200, Thr. 200	0.5	0.2	0.1
Totals - - -	283.5	100.0	24.2

From these tests several interesting facts may be noted. From C_1 we find that 98·3% of the rock material passes through the 100 mesh. Test C_2 shows 40·3% on 100 mesh, while 63·7% is between the 60 mesh and 150 mesh. 88·8% lies between 40 mesh and 200 mesh, there being 12·9% on 60 mesh and 12·2% on 200 mesh. Test No. C_1 should have taken out all the material finer than 200, but we find 4·6% in test C_2, 0·2 in test C_3 and a trace in tests No. C_4 overflow and spigots. Thus we might examine the other tests in the same manner and we should find that in no case has the classification been perfect. It is interesting to note the gradual rise of the quantity of coarse material, from a mere trace on the 20 mesh in C_1 to 44·4 % in C_4 spigot.

Judging from the concentration of the sizes, we take test C_1 as being most efficient; tests C_2, C_3 and C_4 overflow show a greater range in the concentration, though in C_4 overflow 49·5% of the material is on 30 mesh. However, C_4 spigot is somewhat comparable to C_1,—there being 88·8% coarser than 30 mesh. Here indeed, the concentration is within closer limits than in C_1, though in C_1 98·3%, as before mentioned, is finer than 100 mesh.

From Table 3 we find that about 10·82% passes through 200 mesh; in the tests under discussion, the feed was 293 lbs in weight. Thus we should have about 31·7 lbs. through 200 mesh On addition, we find 27·9 lbs. which agrees very well, considering the approximate analysis of Table 3. Assuming, as is indeed very nearly absolutely correct, that all the material fed was caught in the five classes, the efficiency of test C_1 on the through 200 mesh material is $\frac{23 \cdot 2 \text{ x } 100}{27 \cdot 9} = 88 \cdot 2\%$. This brings up the necessity of deciding what we are to mean by the efficiency of a classification. For obvious reasons it is impracticable to ascertain the efficiency in the latter manner of any tests other than C_1 through 200 mesh. From an examination of the screen analyses, however, we may say that tests C_1 and C_2 should remove all material finer than 100 mesh. We have a total of 108·6 lbs. through 100 mesh. Of this amount 103·5 lbs are produced by C_1 and C_2,—showing a combined efficiency of 95·3%.

This is very unsatisfactory, however, especially when we try to analyse the remaining tests in the same light so that for our purposes by "efficiency of classification" shall be understood, the percentage of material between certain limits.

Comparing Table 4 with Table 6, test C_1, we notice that by using the ¼″ orifice instead of the 5-16″ orifice, we reduce the percentage of material coarser than 60 mesh from 7·5 to 0·4; that a narrower range of concentration is obtained; and that 75·6 per cent. is through 150 mesh in C_1 as compared to 53·5 % in Table 4.

It was next decided to reverse the operations and to make the spigot discharge the finished product in each case.

This method is much more convenient as the over-product can be directly pumped back to the feed cone for the next run; further, each test can be completed in one operation, as the spigot product will be much less in quantity and the classifier will hold it all.

Ten runs in all were as follow:—

TABLE 7.

Test No.	Hydr'lic water in galls./min.	Feed-rate, wet in lbs./min.	Feed-rate, dry.	Feed-water galls./min.	Total water	(b) Time of run.	(a) Wgt. of prodt. in lbs.	Actual feed rate a÷b.
T_1	3·32	11·00	6·62	0·44	3·76	52¼′	10·00	5·18
T_2	2·69	12·38	7·26	0·51	3·20	46′	30·44	5·70
T_3	1·92	9·50	5·88	0·36	2·28	45′	55·50	5·18
T_4	"	11·12	6·76	0·44	2·36	......	33·94	
T_5	"	10·50	6·62	0·39	2·31	......	13·00	
T_6	"	8·50	5·26	0·32	2·24	......	6·88	
T_7	1·08	10·12	6·38	0·37	1·45	22′	30·94	5·55
T_8	"	8·26	5·22	0·30	1·38	26¼′	18·19	5·70
T_9	"	6·00	3·62	0·24	1·32	16′	13·13	4·56
T_{10}	0·24	7·50	4·62	0·29	0·53	11¾′	32·50	5·10
T_{10}	Overflow	....	....	.....			27·56	
							272·08	

Only six classes were actually made in the first instance; but after starting the tests, the writer decided to run the feed over again using the same amount of hydraulic water in order to ascertain what was the effect on the classification caused by the elimination of the coarser particles. Thus T_3, T_4, T_5, T_6 form one class; T_7 T_8, T_9, also form one class.

This will be studied later. Screen analyses were made of the feed to test T_1 and of the finished products of the other runs.

These analyses resulted as follow:—

TABLE 8.

FEED TO TEST NO. T_1.*

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	280·0	100·0	272·0
On 20..................	24·0	8·6	23·5
30..................	48·0	17·3	47·0
40..................	20·0	7·2	19·6
60..................	32·0	11·5	31·3
100..................	56·0	20·2	55·0
150..................	39·0	14·0	38·2
200..................	36·0	12·9	35·2
Th. 200..................	23·0	8·3	22·5
Totals...............	278·0	100·0	272·3

TESTS NO. T_1 AND T_2.†

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	204·0	100·0	40·4
On 20..................	108·0	53·0	21·4
30..................	79·0	38·6	15·6
40..................	10·0	4·9	2·0
60..................	55·0	2·4	1·0
100..................	2·0	1·0	0·4
150..................	....	....	....
200.................. } Th. 200..................	0·5	0·2	0·1
Totals...............	204·5	100·1	40·5

TEST NO. T_3.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	234·0	100·0	55·5
On 20..................	36·0	15·6	8·7
30..................	112·0	48·7	27·0
40..................	36·0	15·6	8·7
60..................	28·0	12·1	6·8
100..................	14·0	6·1	3·4
150..................	3·0	1·3	0·7
200 } Th. 200	1·5	0·5	0·3
Totals................	230·5	99·9	55·6

* It will be shown later that this sample cannot have been correctly taken. The results are given, however, for what they are worth.

† Tests T_1 and T_2 were combined because of the small amount of product produced by T_1.

TEST NO. T_4.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	300·0	100·0	33·9
On 20	16·0	5·3	1·8
30	101·0	34·1	11·6
40	54·0	18·2	6·2
60	64·0	21·5	7·3
100	40·0	13·3	4·5
150	10·0	3·2	1·1
200	9·0	3·2	1·1
Th. 200	3·0	1·1	0·4
Totals	297·0	99·9	34·0

TEST NO. T_5.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	253·0	100·0	13·0
On 20	36·0	2·5	0·3
30	70·0	27·7	3·6
40	45·0	17·8	2·3
60	69·0	27·2	3·5
100	50·0	19·8	2·6
150	10·0	3·9	0·5
200	2·5	1·1	0·2
Th. 200	0·3		
Totals	252·8	100·0	13·0

TEST NO. T_6.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	165·0	100·0	6·9
On 20	1·0	0·6	...
30	27·0	16·5	1·1
40	31·0	18·9	1·3
60	54·0	32·9	2·3
100	42·0	25·6	1·8
150	8·0	4·9	0·3
200	1·0	0·6	...
Th. 200	nil		...
Totals	164·0	100·0	6·8

TEST No. T_7.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	315·0	100·0	30·9
On 20	0·5	0·1	...
30	9·0	2·9	0·9
40	23·0	7·3	2·5
60	76·0	24·3	7·5
100	125·0	40·0	12·4
150	46·0	14·6	4·5
200	25·0	8·0	2·5
Th. 200	9·0	2·9	0·9
Totals	313·5	100·1	31·0

TEST No. T_8.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	164·0	100·0	18·2
On 20	nil	.....	....
30	1·0	0·6	....
40	6·0	3·6	0·6
60	29·0	17·8	3·2
100	75·0	45·6	8·3
150	29·0	17·7	3·2
200 } Th. 200 }	24·0	14·6	2·7
Totals	164·0	99·9	18·0

TEST No. T_9.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	297·0	100·0	13·1
On 20	nil	.....	...
30	0·8	0·2	0·1
40	3·5	1·2	0·2
60	34·0	11·8	1·5
100	145·0	49·0	6·4
150	66·0	22·3	2·9
200	36·0	12·3	1·6
Th. 200	10·0	3·4	0·5
Totals	295·3	100·2	13·1

TEST NO. T_{10}.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	257·0	100·0	32·5
On 20	nil	.....	....
30 } 40 }	1·0	0·4	....
60	7·0	2·7	0·9
100	87·0	33·9	11·0
150	79·0	30·8	10·0
200	67·0	26·1	8·5
Th. 200	16·0	6·2	2·2
Totals	257·0	100·1	32·6

TEST T_{10} OVERFLOW.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	255·0	100·0	27·6
On 20	nil	.....	....
30 } 40 } 60 }	1·0	0·4	....
100	38·0	14·9	4·1
150	73·0	28·8	7·9
200	101·0	39·9	11·1
Th.	41·0	16·1	4·4
Totals	254·0	100·1	27·5

From the screen analysis of the feed we find that there should be 23·5 lbs on 20 mesh. On adding up the various amounts on 20 mesh in the several tests we find 32·2 lbs. As the screen analyses were made with considerable accuracy, the error must have occurred in taking the feed sample. This conclusion is confirmed by the fact that if we total the successive products on 30 mesh, etc., we find the same discrepancies.

In tests "T_1 and T_2," we have 21·4 lbs on 20 mesh, giving a recovery of $\frac{21 \cdot 4}{32.3}$ x 100 = 66·5.% This does not compare very favourably with the recovery in the similar case of C_1 of 88·2%. The cause of the difference may perhaps be that the hydraulic water in tests T_1 and T_2 was more or less at the transition point; this would seem probable from an examination of the screen analysis of T_1 and T_2, for, while 53·8% is on 20 mesh, 38·6% is on 30 mesh and only 4·9% on 40 mesh. However, as the purpose was to get as even a division as possible, the amount of hydraulic water could not be altered.

According to our definition of efficiency, the efficiency of the classification of "T_1 and T_2" is 91·6% as compared to 98·3% in case of C_1. In fact most of the "T" runs show a wider range of concentration and hence lower efficiency than was the case in the "C" tests. Hence it would seem better to start with a low hydraulic current and take out the fines; increasing the water supply at each stage.

As already remarked, it is hardly fair to compare the "T" tests with the "C" tests, because the former were partially occasioned by a desire to find out what would be the effect on the classification should the hydraulic water remain constant. Tests T_3, T_4, T_5 T_6 form a set illustrating this point. We notice that a very appreciable amount of spigot product is produced each time though in a constantly diminishing ratio. At first this result gave considerable anxiety as it seemed to indicate that the classifier might be very inefficient; but the writer now feels able to offer a satisfactory solution. The tests show that as the percentages of fines increases, the feed-rate diminishes to some extent. In the "T" tests, the coarser material was taken out first, thus causing the ratio of fines to increase. This diminished feed causes the working area in the classifier to increase, hence giving an apparently slower rising current. Further, the feed is becoming successively finer and within certain limits, more compact, taking up less space in the classification column. Until this effect is counter-balanced by the greater lightness of the particles, a settling will take place due to the apparent decrease of the rising current.

Tests T_7, T_8, T_9, show the same results, especially the diminishing feed-rate. The screen analyses also bear out this theory, for each succeeding analysis shows a much greater percentage of fines than the preceding analysis.

In connection with these two series of tests it might be interesting to attempt to determine the sliming effect of the repeated pumping. It is safe to assume that the screen analysis of the feed in Table 3, although only approximate, is none the less fairly accurate. From Table 3, we find that 35·73% is through 100 mesh. The weight of the feed in Table 5 is 293 lbs., thus there should be 104 lbs. through 100 mesh in the various tests. On addition we have 119 lbs.,—an addition of 15 lbs. Most of this was probably caused by the attrition in pumping. The material was pumped four times, each successive pumping being less in weight by the amount of the finished product. We may calculate to the total amount pumped thus:—

Original pumping or feed to C_1		293 lbs.
Feed to C_2	293–66	227 "
" " C_3	227–99	128 "
" " C_4	128–70	58 "
		706 lbs.

Now in pumping 706 lbs, 15 lbs of fines were produced.

$$\therefore \text{The sliming effect is } \frac{15 \times 100}{706} = 2 \cdot 12\%.$$

It is unfortunate that the error in the feed sample to the "T" tests (Table 8) renders it impossible to make a similar investigation for the second series of tests; but it is probable that the sliming is considerably less, inasmuch as the coarser particles are most likely to slime and these particles are taken out during the first operations.

It seemed advisable to attempt to combine the advantages of the two sets of tests and to this end a third trial series was run. In this series the fines were first taken out, making the first overflow the finished product, but in all succeeding runs the spigot product was the finished product.

By this method it was hoped to eliminate any serious overflow losses, to reduce attrition in the pumping, to facilitate operations and possibly even to increase the efficiency of classification.

Seven runs in all were made, giving eight classes; P_2 and P_3; P_4 and P_5; P_6 and P_7 were run without changing the hydraulic water for the second test.

The results follow:—

TABLE 9.

Test No.	Hydr'lic water in galls./ min.	Feed rate, wet in lbs. min.	Feed rate, dry.	Feed-water.	Total water.	Time of run.	Weight of prodt.	Actual feed-rate a ÷ b.
P_1	0·24	10·12	6·12	0·40	0·64	28′	23·87	5·03
P_2	2·70	12·62	7·00	0·56	3·26	19′	20·06	6·16
P_3	"	11·62	6·62	0·50	3·20	15½′	11·63	6·25
P_4	1·55	11·76	6·76	0·50	2·05	13½′	26·56	6·30
P_5	"	11·62	6·76	0·49	2·04	9½′	11·06	6·20
P_6	0·63	....	......	......	......	8′	30·44	5·97
P_7	"	10·26	6·12	0·41	1·04	3′	8·00	5·79
P_7	Overflow	....	......	......	......	....	9·37	
					Total	weight	140·99	

These tests show the remarkable difference in the feed rate between P_1 and P_2. P_1 is the test in which the overflow product was the finished product, while P_2 is the coarsest run of the series. Runs P_2, P_3, P_4 and P_5 do not show much variation of feed, but the tendency to a decrease of feed is perhaps intimated. The remaining tests, however, have a diminishing feed rate.

The amount of feed-water is almost constant, especially for the four centre runs, P_2, P_3, P_4 and P_5, but is considerably more in quantity than was the case in Table 7. This is probably due, as before explained in connection with the T tests, to the larger space between the rock particles. Test P_1, having the fines in it, shows only 0·40 gallons of feed water per minute, while test P_2 containing the coarsest particles, shows the greatest quantity of food water of any of the tests, viz., 0·56 gallons per minute.

From Table 5, we find that the feed water increased steadily from 0·25 gallons per minute in the case of C_1 to 0·73 gallons per minute in the case of C_4. This further proves our contention in the C tests the finished production in each case was the overflow product and the feed was successively coarser.

Screen analyses were made of the runs in Table 9 and resulted as follow:—

TABLE 10.

TEST NO. P_1.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	250·0	100·0	23·9
On 20........	nil	.....	
30 } 40 } 60 }	1·0	0·4	0·1
100........	12·0	4·8	1·1
150........	37·0	14·8	3·5
200........	92·0	36·8	8·8
Th. 200........	108·0	43·2	10·3
Totals........	250·0	100·00	23·8

TEST NO. P_2.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	243·0	100·0	20·1
On 20........	112·0	46·2	9·1
30........	104·0	42·8	8·6
40........	15·0	6·2	1·2
60........	8·0	3·3	0·7
100........	2.5	1.0	0 2
150........	.....	.....	
200........	0·5	0·4	0·1
Th. 200........			
Totals........	242·5	99 9	19·9

TEST NO. P_3.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	310·0	100·0	11·6
On 20........	119·0	38·6	4·5
30........	149·0	48·2	5·6
40........	24·0	7·7	0·9
60........	13·0	4·2	0·5
100........	3·5	1·1	0·1
150 } 200 }	0·5	0·2	....
Th. 200........	nil		....
Totals........	309·0	100·0	11·6

TEST No. P_4.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	256·0	100·0	26·6
On 20	44·0	17·2	4·6
30	123·0	48·2	12·8
40	36·0	14·1	3·7
60	32·0	12·5	3·3
100	16·5	6·4	1·7
150	3·0	1·2	0·3
200	1·0	0·4	0·3
Th. 200	nil	.....	....
Totals	255·5	100·0	26·5

TEST No. P_5.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	254·0	100·0	11·1
On 20	14·0	5·5	0·6
30	93·0	36·6	4·1
40	52·0	20·4	2·3
60	54·0	21·2	2·4
100	34·0	13·4	1·5
150	5·5	2·2	0·2
200	1·0	0·4	....
Th. 200	0·5	0·2	....
Totals	254·0	99·9	11·1

TEST No. P_6.

Mesh.	Weight in gms.	Per cent.	Weigh of product in lbs.
....	281·0	100·0	30·4
On 20	1·5	0·5	0·2
30	28·0	9·9	3·0
40	39·0	13·9	4·2
60	75·0	26·7	8·2
100	95·0	33·9	10·3
150	33·0	11·8	3·6
200	8·0	2·8	0·8
Th. 200	1·0	0·5	0·1
Totals	280·5	100·0	30·4

TEST NO. P_7.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	211·0	100·0	8·0
On 20	nil	.....	....
30	2·5	1·2	0·1
40	7·0	3·3	0·3
60	33·0	15·6	1·2
100	106·0	50·3	4·0
150	40·0	18·9	1·5
200	20·0	9·5	0·8
Th. 200	2·5	1·2	0·1
Totals	211·0	100·0	8·0

TEST NO. P_7.—OVERFLOW.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	244·0	100·0	9·4
On 20	nil	.....	..
30 } 40 }	1·0	0·4	
60	6·0	2·5	0·2
100	69·0	28·3	2·6
150	84·0	34·5	3·2
200	64·0	26·2	2·5
Th. 200	20·0	8·1	0·8
Totals	244·0	100·0	9·3

From these tests we find that a total of 11·4 lbs passed through 200 mesh. Test P_1 produces 10·3 lbs. of this showing a recovery of 90·3%, which is a little better than was obtained in Table 6. The beneficial effect on the classification of the removal of the fines is shown by a comparison of Tables 8 and 10. Tests T_1 and T_2 show a little better efficiency, giving 91·6% recovery coarser than 30 mesh as against 90·0 % in the case of P_2. But T_3 shows only 64·3% coarser than 30 mesh whereas in P_3 we have 86·8%. Again in T_4 we have a concentration of 87·2% between 20 mesh and 100 mesh, whereas in P_4 we have 94·8%, 48·2% of which is on the 30 mesh.

On the whole, the "P" tests were rather better than either of the other two series, and it was accordingly decided to use this method on the ore which was to be prepared for the table experiments.

Classification of the Bruce Mines Ore.

About three tons of the Bruce Mines Ore were crushed through 18 mesh. Most of the ore had already been crushed to various sizes, in carrying out certain previous tests; but whatever was coarser than 18 mesh was crushed either in the Comet gyratory breaker or the Huntingdon Mill or both.

The ore was divided into three portions: one for Mr. Cox to be treated on the Callow screen; one for the writer for purposes of classification; and one to be held in reserve for natural feed runs and the like.

TABLE 11.

Classification of Bruce Mine Ore.

Test No.	Hy. water in galls./ min.	Feed-rate—wet in lbs. min.	Feed-rate—dry.	Feed - water.	Total water.	Time of run	Wgt. of product in lbs.	Ore treated in lbs.
1. A	0·42	10·00	6·06	0·40	0·82	74½′	106	520
B	"	10·50	6·38	0·40	0·82	72½′ }	171	507
C	"	9·38	6·00	0·38	0·80	63 ′ }		430
D	"	11·00	6·50	0·46	0·80	73 ′	102	513
						Totals	379	1,970
2. A	2·34	13·26	7·88	0·54	2·88	65 ′ }		
B	"	13·00	7·88	0·51	2·85	60 ′ }	262	
C	"	13·50	8·00	0·55	2·89	67 ′ }		
3. A	1·78	13·38	7·92	0·54	2·32	51 ′ }		
B	"	12·38	7·62	0·48	2·26	50 ′ }	281	
C	"	13·00	7·88	0·56	2·34	50 ′ }		
4. A	1·28	12·50	7·76	0·47	1·75	43 ′ }		
B	"	11·88	7·50	0·43	1·71	38 ′ }	282	
C	"	13·24	8·12	0·51	1·79	40 ′ }		
5. A	0·80	12·12	7·50	0·46	1·26	27 ′ }		
B	"	11·54	7·26	0·43	1·23	26 ′ }	299	
C	"	12·12	7·50	0·46	1·26	26 ′ }		
					Run 5 overflow		295	
			Total weight of products				1,798	
			Weight of feed samples ..				87	
							1,885	
						Loss.....	85	4·3%
							1,970	

As Mr. Cox had decided to make six sizes, the writer decided to make six classes by the classifier so that the two sets of trials should be as nearly as possible in parallel.

Two separate samples of the ore were taken for purposes of screen analyses and assaying.

As the cone would only hold about 500 lbs., it was necessary to treat the ore in four lots.

With the exception of the large amount of the overflow product in run No. 1, the classes are very equal in weight. The feed to run No. 1 was dry, but in all other cases it was wet so as to save time.

While the loss may look somewhat large in quantity, yet it is really comparatively little when we consider the amount of handling and pumping that was necessary and the consequently large production of impalpable slimes.

These runs also give further proof, if necessary, of our contention that the presence of fines lowers the feed-rate.

The feed rates in runs 1A, B, C and D are fairly uniform, averaging about 6·36 lbs. per minute. Referring to the other runs we find that in general, runs 2A, B and C, being the coarsest runs, have the greatest feed-rate, averaging about 7·92 lbs. per minute. As the feed gradually becomes finer, the feed-rate diminishes steadily, until in the last run, No. 5, it is 7·42 lbs per minute.

The feed water also agrees with the theory. In Run 1 it averages ·41 gallons per minute, jumping to 0·52 gallons per minute in Run 2 and thence decreasing to 0·44 gallons per minute in the last run, No. 5.

In all the screen analyses on the ore the standard screens of the I.M.M. were used and the mechanical screening machine was employed where practicable, as will be explained later. All screen samples weighed 200 gms. except where otherwise stated and the screening was done in thirty minutes. Samples were taken of the six classes and analyses made as given in Table 12.

As Mr. Cox decided to use the 20, 30, 40, 60 and 100 mesh screens on the Callow machine, the analyses of classified products were all run with the same set of meshes.

TABLE 12.

SCREEN ANALYSES OF RUNS IN TABLE 9.

Feed to run No. 1:—

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	150·0	100·0	1,798·0
On 20....................	20·0	13·3	239·0
30....................	39·1	26·1	470·0
40....................	22·5	15·0	270·0
60....................	25·3	16·9	304·0
100....................	22·2	14·8	266·0
Th. 100....................	20·8	13·9	250·0
Totals....................	149·9	100·0	1,799·0

RUN NO. 1.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	200·0	100·0	379·0
On 20....................	nil	.....	.....
30....................	0·5	0·2	0·8
40....................	2·7	1·3	4·9
60....................	24·5	12·3	46·6
100....................	73·7	36·9	140·0
Th. 100....................	198·5	49·3	187·0
Totals....................	199·9	100·0	279·3

RUN NO. 2.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	200·0	100·0	262·0
On 20....................	86·8	43·4	114·0
30....................	80·1	40·1	105·0
40....................	21·0	10·5	27·5
60....................	0·1	4·6	12·0
100....................	2·3	1·1	2·9
Th. 100....................	0·7	0·3	0·8
Totals....................	200·0	100·0	262·2

RUN NO. 3.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	200·0	100·0	281·0
On 20....................	57·7	28·9	81·4
30....................	87·0	43·5	122·5
40....................	31·0	15·5	43·6
60....................	18·1	9·1	25·6
100....................	4·9	2·5	7·0
Th. 100....................	1·0	0·5	1·4
Totals.................	199·7	100·0	281·5

RUN NO. 4.

Mesh.	Weight of gms.	Per cent.	Weight of product in lbs.
....	200·0	100·0	282·0
On 20....................	26·1	13·1	37·0
30....................	84·9	42·5	120·0
40....................	43·3	21·7	61·2
60....................	30·4	15·2	42·9
100....................	12·2	6·1	17·2
Th. 100....................	2·6	1·4	3·9
Totals.................	199·7	100·0	282·2

RUN NO. 5.

Mesh.	Weight in gms.	Per cent.	Weight of product in lbs.
....	200·0	100·0	299·0
On 20....................	4·8	2·4	7·2
30....................	49·3	24·7	74·0
40....................	52·9	26·5	79·3
60....................	55·6	27·8	83·2
100....................	28·0	14·0	41·9
Th. 100....................	9·1	4·6	13·7
Totals.................	199·7	100·0	299·3

RUN NO. 5.—OVERFLOW.

Mesh.	Weight in gms.	Per cent.	Weight in product in lbs.
....	200·0	100·0	295·0
On 20..........	0·3	0·1	0·3
30..........	7·5	3·7	10·9
40..........	27·3	13·7	40·5
60..........	69·4	34·7	102·5
100..........	60·4	30·2	89·1
Th. 100..........	35·0	17·5	51·7
Totals..........	199·9	99·9	295·0

The analysis of the feed shows the material to be very evenly distributed among the various sizes with the exception of the "on 30 mesh" product which is nearly double the amount of the others. Run 1 shows a concentration of 86·2% through 60 mesh and 98·5% through 40 mesh.

Run No. 2 gives a concentration or efficiency of 83·5% on 30 mesh and 94·0% on 60 mesh.

Run No. 3 shows a large concentration on the 30 mesh amounting to 43·5%, while Run No. 4 runs it very close with 42·5% on the 30 mesh.

Those screen analyses were made with very great accuracy, mainly due to the efficiency of the screening machine, so it is possible to investigate the sliming of the ore with considerable confidence.

The coarse 20 mesh material does not seem to have suffered much. This may be explained by the fact that the feed material on 20 mesh was proportionately coarser than the other products, since it had been previously crushed to just pass 18 mesh. Thus it could be considerably reduced and still remain on the 20 mesh screen. Further, the coarse material is taken out during the second and third runs.

Accordingly, we may expect the "on 30 mesh" and "on 40 mesh" material to show the greatest losses.

This proves to be the case: the feed analysis shows 470 lbs. on 30 mesh, but on addition of the several runs we find only about 433 lbs.; similarly on 40 mesh we have about 247 lbs. instead of 270 lbs. Now "through 40 mesh" we should get 820 lbs. whereas we find 869·4 lbs., an increase of 49·4 lbs. We may safely assume that this was due to pumping.

Feed to Run 1	1798 (excluding losses)
" " " 2	1419
" " " 3	1157
" " " 4	876
" " " 5	594
Total lbs. pumped	5844

Now, in pumping 5,844 lbs., 49·4 lbs of fines were produced. Thus the sliming effect is $\frac{49 \cdot 4 \times 100}{5844} = 0 \cdot 84\%$.

It will be remembered that, in the case of the preliminary tests of Table 5. in which the fines were successively taken out, the feed becoming coarser and coarser, the sliming effect was 2·12%. Of course it is not fair to compare the two without making some allowance for the difference of accuracy in the screen analyses and also the difference in the rock. As regards the latter, however, it may be stated that the syenite rock in question was extremely hard and probably resisted attrition, as well or better than the ore.

In any event, the result is very satisfactory as showing the efficiency of the method used in reducing attrition. Further, it may be of sufficient interest to point out that the greatest increase in fines was found on the 100 mesh; there being a total of 298·1 lbs. as against a feed of 266·0 lbs., a difference of 32·1 lbs. or 65% of the total increase of fines.

An attempt was made to effect a concentration of the chalcopyrite by classification and 57 lbs of the ore was fed into the classifier. About half a pound of spigot product was produced but it contained practically no copper.*

Run No. 7 was made on some of the reserve ore. It was the purpose to divide the ore into two classes and treat each on the Wilfley Table. The data follow:—

* The chalcopyrite in this ore is very flaky and therefore unsuitable for classified or jig concentration.

TABLE 13.

Run No. 7.—Weight of ore treated	414 lbs.	
Feed rate, wet	12·12 lbs. per min.	
" " dry	7·38 " " "	
" water	4·74 " " "	
Time of run	52 minutes	
Hydraulic water	0·8 gals. per min.	
Total water	1·3 " " "	
Weight of spigot	250 lbs.	
Overflow	151 lbs.	
	401 lbs.	
Loss	13 lbs= 3·1%.	

PART III.

THE RELATIVE MERITS OF SCREEN-SIZED, CLASSIFIED AND NATURAL FEEDS FOR THE WILFLEY TABLE.

In the concentration of finely ground ore, the Wilfley Table is, on the whole, the most successful machine in use. Since its introduction in 1896, it has revolutionised ore-dressing processes and has made it possible to treat ores of certain familiar and important types more cheaply and effectively than ever before.

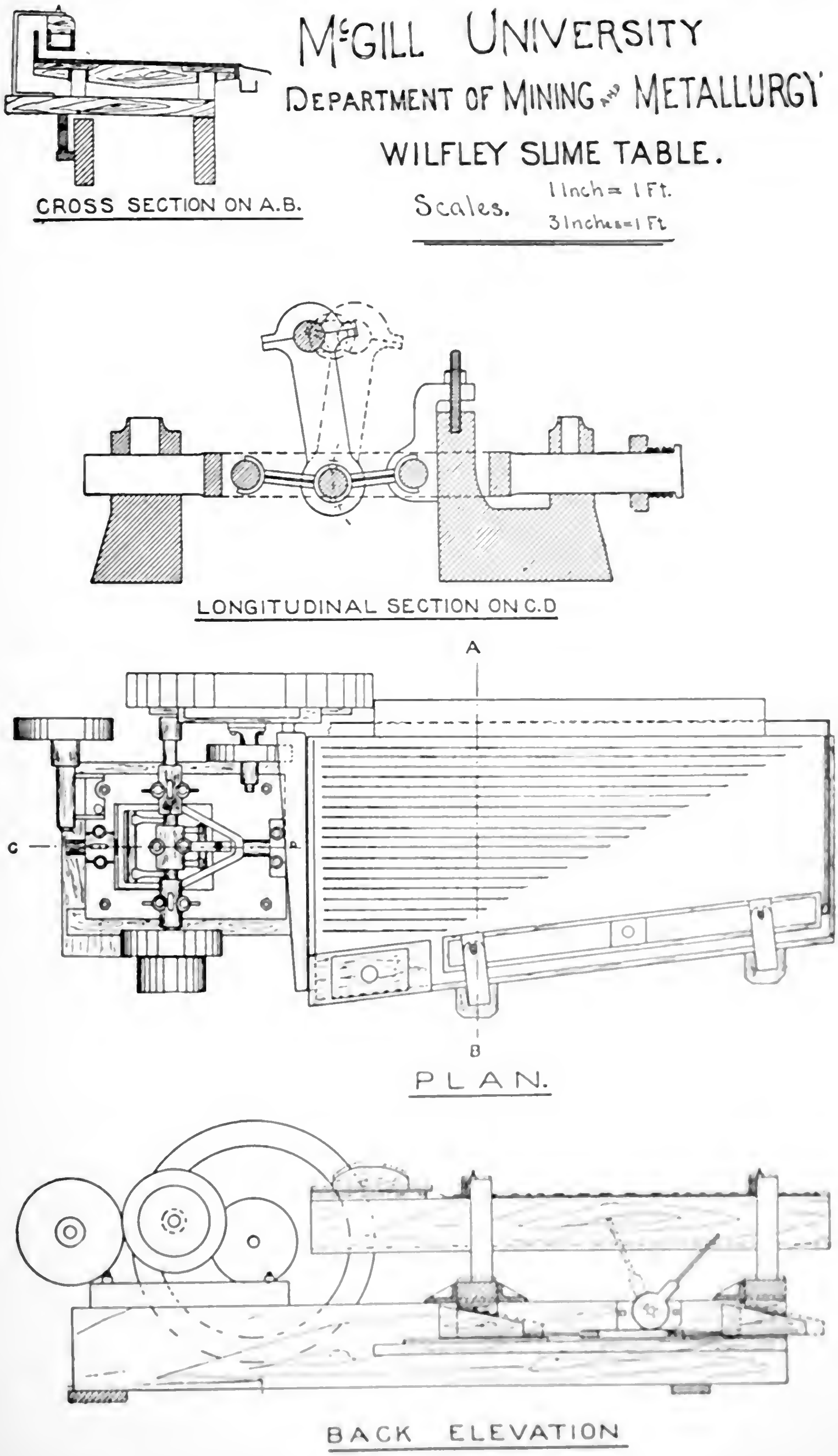
Numerous other tables are now on the market, each claiming to be better than the others. Doubtless each table has its points of superiority; but nevertheless they are practically all jerking riffles of the Wilfley type and in a general way possess the same advantages and suffer the same limitations as the original Wilfley.

The mill designer who wishes to treat his fine pulp on tables of this type, has three courses open to him: He may

(1) Divide the material into grades according to size, irrespective of specific gravity by fine screening.

(2) Divide the material into grades according to size in conjunction with specific gravity, by hydraulic classification.

(3) Feed the pulp as it comes without other treatment than to ensure its being fine enough for successful treatment by the use of some comparatively coarse screen or classifier to divert


McGILL UNIVERSITY
DEPARTMENT OF MINING AND METALLURGY
WILFLEY SLIME TABLE.
Scales. 1 Inch = 1 Ft. 3 Inches = 1 Ft
CROSS SECTION ON A.B.
LONGITUDINAL SECTION ON C.D
A
C
D
B
PLAN.
BACK ELEVATION

the coarse grains to some other type of separator (usually a jig). In this case the major part of the very finest material is usually also removed by some desliming apparatus before the pulp reaches the tables.

Each course has its advocates, although (2) is favoured by the majority of writers on ore dressing theory; but although the phenomenal success of the Wilfley type of table has naturally enough resulted in its very general use for all classes of work, this very success is also responsible for the fact that very little exact information is available as to the true character of its work as a separator, and as the best method of preparing its feed.

It was in an endeavour to obtain such information in regard to the Wilfley Table that led Prof. R. H. Richards to run a very careful and instructive series of tests at the Massachusetts Institute of Technology.*

There are three theories as to the best feed for tables: namely, natural or mixed pulp; screened feed; and classified feed. The results of Prof. Richard's tests are in his opinion in favour of classified feed. This claimed superiority is at best very slight and is based upon experimental work and deduction therefrom which are not above criticism. It has seemed therefore desirable to attempt to throw further light upon the subject.

The experimental Wilfley Table used in these tests is illustrated in Plate I, and is exactly like the commerical table in all respects, except that it is smaller, being seven feet long by two and a half feet wide at head end and three feet at feed end. The ordinary full-sized table is about sixteen feet long by seven feet wide. The table used by Prof. Richards had a working area of only two by four feet and the riffle grooves were cut into the wooden table top instead of being made of strips tacked on and rising above the flat surface of linoleum.

Prof. Richards in his "Ore-Dressing" Vol. III, p. 1469, describes the operation of the Wilfley table. Rather more briefly, his arguments are as follow:—

The bed of pulp when stratified on the table top ranges in depth from 1 grain at its margin on the cleaned ore plane, to a maximum of 10 to 20 grains in the riffles at a point from 15 to 30 inches from the top of the tip ends of the riffle cleats.

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*Transactions—American Institute of Mining Engineers. Volume xxxviii, pp. 556-580, and xxxix, pp. 303-315.

By reason of having a deep bed where the riffles are deep, two favourable conditions exist. Firstly, a gentle agitation can be maintained between the riffle cleats which opens up the deep bed and gives any grains of value an opportunity to fall into the lower layers. Secondly, the upper layers of clean waste can then be readily washed away without interfering with the concentration or progression of the lower layers.

As soon as the pulp loses the support of the edge of each riffle cleat the wash water carries the waste and a small part of the concentrates to the next lower riffle. As the pulp advances along the riffles, which steadily diminish in depth, waste is washed out. Finally the bed becomes so shallow near the ends of the riffle cleats that the wash water carries some mineral off with the waste. This shallow area is the medium of transition from the deep bed of the cleaning plane to the completely cleaned ore of the cleaned ore plane, and is generally called the middle area, beyond which the balance of the heads, now completely cleaned, advance across the plane surface in a band, supported by the diagonally cut off riffle cleat tips, and by the pulp between these tips.

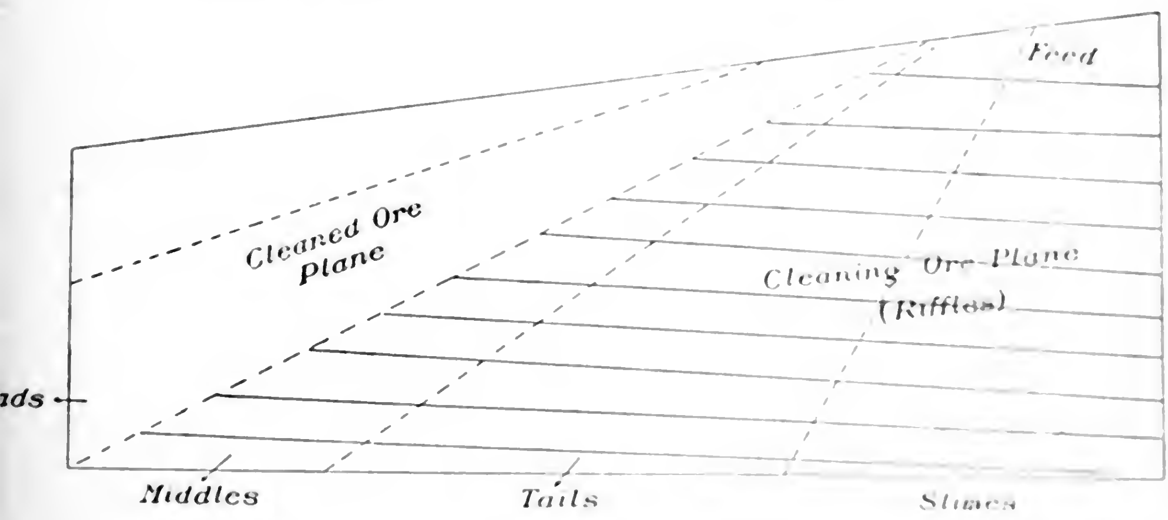


FIG. IV.

In the commercial tables and also in the table used in these tests, the riffle cleats are tacked upon the plane surface of the linoleum. Thus the cleaning plane makes a very slight angle with the cleaned ore plane. Virtually we have a very small valley between the two narrow elevated planes which causes a deepening of the bank of sand and narrows the fan of concentrates. Theoretically, the nearer we can get the pulp to be one grain deep on the riffle cleats, the more perfectly will the grains be treated, each according to its own law. Prof. Richards is of the opinion that on a experimental seven foot table, such as we used, this banking up is so serious as to interfere with good work, although almost negligible on the large tables. The table used by Prof. Richards had, as already stated, the riffles made by cutting grooves into the surface. By this means he believes the small table he used gave as good results as the large table, since both cleaning plane and cleaned ore plane are then one and the same. The authors have not had an opportunity to use Prof. Richards' table; but from experiments with very similar small tables, and with full sized Wilfleys, they are led to believe that he exaggerates the difficulties with the seven foot table, which they find in practice to very closely approximate the full sized apparatus, if properly adjusted.

Prof. Richards made two series of tests: one upon galena and quartz, the other upon cupriferous pyrite and quartz; but as our experiments were conducted on ore of the latter character only, we shall confine our attention almost entirely to the latter series of tests which appear in the T.A.I.M.E. for 1909, Vol. 39, p. 303.

Being unable to obtain any pure chalcopyrite, Prof. Richards used a cupriferous pyrite nearly pure, containing 8·80% of copper. Hence he states that it should be borne in mind that the material concentrated was of low copper content, the feed averaging about 1% copper. The writer would ask that in studying his tests, it be remembered that the Bruce Mines ore averaged but 2·42% of copper in the form of chalcopyrite. Despite the comparative richness in copper of this feed used in these tests, it would seem that the advantage was rather on Prof. Richards' side, inasmuch as not only did his mineral have an appreciable greater specific gravity, but his feed would contain much more of the cupriferous pyrite than our feed contained chalcopyrite.* In the case of Prof. Richards' tests, feed containing only 1·0% copper would contain nearly 12% of the cupriferous pyrite. The richest feed in any of our runs was in that of run S_6, containing about 15% of chalcopyrite, while our average feed contained about 5·7% chalcopy-

* Since chalcopyrite ordinarily has about 33 % copper.

rite. The advantage of having a high mineral content is that the recovery is considerably higher, the little loss in the tailings being nearly constant in all runs of similarly sized material irrespective of the mineral content. Further, and this in our opinion is a very grave defect in his experiments, Prof. Richards had no middlings in the proper sense of the term, since his feed was merely a mixture of pure quartz and pure mineral with no grains containing both.

For our tests we used the regular ore which contained the usual middles material, and in no case did we re-run our middles product; Prof. Richards did not re-run his middles in the natural feed runs, but in all the screened and classified feeds the middles were continually returned to the table and re-run. (T.A.I.M.E., Vol 38, 1907, p. 560).

As Prof. Richards subsequent comparisons were apparently based on the recovery of concentrates, it seems to the writer with all due respect, that the tests are manifestly unfair, inasmuch as the middles product is part of the true recovery. Further, in the case of the natural feed runs, the material was not first deslimed as is almost unavoidably the case in practice. The Wilfley Table is not suited for treatment of slimes and in the most modern mills the ore is first deslimed before feeding to the Wilfley Table. Furthermore, all the classified and screened feed was apparently deslimed. This also appears to be rather unfair.

Table 14 shows the recovery obtained by Prof. Richards in the natural feed runs of both series of tests:

TABLE 14.

COPPER-QUARTZ TESTS.

(Per cent. of Total Copper.)

Run No.	Heads.	Middles.	Tails.	Slimes.
1	19·3	70·6	6·7	4·4
2	46·6	37·7	8·1	7·6
3	48·1	24·2	14·2	13·4
4	48·1	13·0	19·6	19·3

GALENA-QUARTZ TESTS.

(Per cent. of Total Galena.)

Run No.	Heads.	Middles.	Tails.	Slimes.
1	39·2	53·3	3·8	3·6
2	34·6	57·3	4·7	3·4
3	44·9	42·0	5·4	7·7
4	51·5	27·6	8·2	12·7
5	29·1	67·8	1·6	1·5

Now, if we recalculate these tables on the basis of deslimed ore, add the remaining tests made by Prof. Richards and add a column showing the total recovery in heads and middles we have the following results:

TABLE 15.

COPPER-QUARTZ TESTS.

(Per cent. Total Copper.)

Run No.	Heads.	Middles.	Tails.	Heads and Middles.
1	20·1	73·9	6·0	94·0
2	50·5	40·8	8·7	91·3
3	55·6	28·0	16·4	83·6
4	59·6	16·1	24·3	75·7
5	78·9	21·1	00·0	100·0
6	86·2	13·8	00·0	100·0
7	89·8	10·2	00·0	100·0
8	78·7	21·3	00·0	100·0
9	70·8	29·2	00·0	100·0
10	98·7	1·3	00·0	100·0
11	93·0	6·7	0·3	99·7
12	67·7	28·4	3·9	96·1
13	79·6	16·5	3·9	96·1
14	82·2	16·2	1·6	98·4
15	81·5	16·0	2·5	97·5
16	81·5	14·2	4·3	95·7
17	....	....	....	....

Runs 1 to 4 are on natural feed.
" 5 to 10 " screened feed.
" 11 to 16 " classified feed.

GALENA-QUARTZ TESTS.

(Per cent. Total Galena.)

Run No.	Heads.	Middles.	Tails.	Heads and Middles.
1	40·7	55·3	4·0	96·0
2	35·8	59·4	4·8	95·2
3	48·7	45·5	5·8	94·2
4	59·0	31·6	9·4	90·6
5	29·6	68·8	1·6	98·4
6	87·4	12·0	0·6	99·4
7	96·4	3·6	00·0	100·0
8	97·6	1·8	0·6	99·9
9	96·6	2·3	1·1	98·9
10	90·6	7·9	1·5	98·5
11	94·6	3·1	2·3	97·7
12	98·2	1·5	0·3	99·7
13	81·3	10·7	8·0	92·0
14	88·9	6·0	5·1	94·9
15	86·7	4·3	9·0	91·0
16	90·6	2·9	6·5	93·5
17	79·4	10·7	9·9	90·1

Runs 1 to 5 are on natural feed.
" 6 to 11 " screened feed.
" 12 to 17 " classified feed.

An examination of these results shows that when the combined saving of the heads and middles is taken into consideration, the natural feed runs are at least not completely outclassed by screened and classified feeds.

It is true that in the case of the copper-quartz tests the recovery in the natural feed runs on the finer sizes is considerably below the recovery made on screened and classified feeds; but in the case of the galena-quartz tests the average recovery in the natural runs is very appreciably higher than the recovery obtained in the classified runs, though a little lower than that obtained in the screened feed runs. In either case the total recovery made with screened feed is plainly higher than that obtained on classified feed. In fact when we look at the losses in the tailings, we find that in the Copper-Quartz Tests absolutely no mineral is found in the screened feed runs, a fact which incidentally shows the abnormality of using a feed containing no middles. Prof. Richards does not note this, though he does say that the "tailings on the sized product are decidedly better than those from the classified product."*

Even when we consider heads alone, the recovery in the screened feed runs is appreciably better than in the classified feed runs. Run No. 12 in the Galena-Quartz Tests certainly is very remarkable both from its high recovery and the large quantity of concentrates. Run No. 11 in the Copper-Quartz Tests also shows this though to a somewhat less extent. This appears to be Prof. Richards only reason for giving the preference to the classified feed. Prof. Richards also mentions, however, that the "sized products were prepared under ideal conditions, being dry sized with the greatest care. In the mill, screening wet, the classifier would compare much more favourably with the screens on the sizes which it is best adapted to treat."†

It appears to the writers that the results of Prof. Richards' tests in both his series of runs do not support his conclusions and are rather in favour of the screened feed, especially as nowadays there has arisen a great demand for conservation and high recovery extraction as against the old rule of "take as much as will pay best." Neither would it appear, in the light of the above remarks, that the natural feed is completley outclassed. In fact from a purely economical basis, perhaps the natural feed would give best results.

Apart from all results, however, it seems to the writer that the amounts of ore treated and the rate of feed used in Prof. Richards' tests were probably not of sufficient quantity from which to draw very definite conclusions.

Even if the table used by Prof. Richards does do as good work as a full sized table, by reason of the grooves, it would appear doubtful that the capacity varies as the area of the working surface. In many of Prof. Richards' tests the amount of ore treated was much less than 10 lbs., and the largest test was made on less than 40 lbs., and the unavoidable errors at the beginning and end of the runs must have had a large effect upon the small quantities of material produced. The feed in the largest tests was only 2·2 lbs. per minute; this, of course, gave a test of nearly 20 minutes' duration, but in many of the tests the run lasted only

*(T.A.I.M.E., 1909, Vol. 39, p. 305).

†Ore-Dressing, Vol. 3, p. 1,477.)

a very few minutes—scarcely time enough to get the table in good running adjustment.

Again, is it fair to assume that a feed of even 2·2 lbs. though it is proportional to the size of the table, would give the same results as 30·6 lbs. per minute on the full sized table? It seems to the writers that the action of the table would be totally different; the feed is reduced proportionally to the area of the table, but the size of the grains remains unchanged, and it is probable that the action of the wash-water, the feed-eater, the throw, and the head action of the table would give a very changed condition.

In the following pages the results of the experiments made by the authors will be found tabulated and discussed, and if undue stress is apparently laid on details of the work and evidence of its considerable accuracy, it is because the writers wish to show that they have some justification at least, in arriving at conclusions which are at variance with those heretofore advanced by experimenters and authors of eminence.

In conducting the tests, the table was first adjusted so as to make apparently clean heads and tails. The middles were not returned to the table, as they contained a considerable quantity of grains with included mineral, and in good practice would have been re-crushed and treated separately.

Thirteen tests were then run—six with sized feed prepared by Mr. Cox, as already detailed in Part I, and six with classified feed prepared by Mr. Gibbins, as detailed in Part II. One test was then run with natural feed; but lack of time prevented, for the time being, further tests on this material, although the results of the one test are so interesting that a full series of trials will be carried to completion as soon as practicable.

WILFLEY TABLE RUNS.

TABLE 16.

SCREENED FEED.

	S_1.	S_2.	S_3.	S_4.	S_5.	S_6.
Weight of feed in lbs.	435	335	250	243	181	182
Table inclination	4°51′	4°51′	3°52′	3°08′	2°00′	nil
R. P. M.	272	272	285	272	278	272
Throw	$\frac{7}{8}$″	$\frac{7}{8}$″	11/16″	$\frac{5}{8}$″	$\frac{5}{8}$″	$\frac{1}{2}$″
Feed orifice	$\frac{3}{8}$″	$\frac{3}{8}$″	$\frac{3}{8}$″	5/16″	5/16″	5/16″
Time of run	$26\frac{1}{2}$′	$18\frac{1}{4}$′	15′	$26\frac{1}{4}$′	27′	60′
Rate of feed in lbs./min.	16·4	17·8	16·7	9·4	6·7	3·0
Rate of feed in tons 24 hrs.	11·8	12·8	12·0	6·8	4·8	2·2
Feed water in lbs. /min.	27·57	29·69	28·5	27·5	31·0	26·1
Wash water	52·93	30·57	....	53·5	44·0	75·0
Total "	80·50	60·26	....	81·0	75·0	101·1
Ratio of water to feed	4·9:1	3·4:1	....	8·6:1	11·2:1	33·6:1
Width of heads	1″	2″	4″	4″	6″	8″
" " middles	2″	2″	2″	3″	4″	12″
Weight of heads	17·4	16·9	17·2	21·6	22·9	23·6
" " middles	19·4	22·2	12·2	14·2	15·4	58·0
" " tails	393·0	295·0	219·0	203·0	140·0	92·0
Total	429·8	334·1	248·4	238·8	178·3	173·6
Loss	5·2	0·9	1·6	4·2	2·7	8·4
Loss per cent	1·2	0·3	0·6	1·7	1·5	4·6

TABLE 17.

CLASSIFIED FEED.

	C_1.	C_2.	C_3.	C_4.	C_5.	C_6.
Weight of feed in lbs.	259	286	251	296	295	378
Table inclinn	4°50′	5°01′	4°28′	4°09′	2°45′	1°25′
R. P. M.	268	272	272	272	276	272–320
Throw	$\frac{7}{8}$″	$\frac{7}{8}$″	11/16″	$\frac{5}{8}$″	$\frac{5}{8}$″	$\frac{1}{2}$″
Feed orifice	$\frac{3}{8}$″	$\frac{3}{8}$″	5/16″	5/16″	5/16″	5/16″
Time of run	15′	17′	23′	29′	30′	75′
Rate of feed in lbs. /min.	17·2	16·5	10·9	10·2	9·9	5·0
Rate of feed in tons/ 24 hrs.	12·4	11·9	7·8	7·3	7·1	3·6
Feed water in lbs /min.	26·6	35·2	36·2	35·2	34·0	57·0
Wash "	55·4	32·8	42·8	33·0	41·0	87·0
Total water	82·0	68·0	79·0	68·2	75·0	144·0
Ratio of water to feed	4·8:1	4·1:1	7·2:1	6·7:1	7·6:1	28·8:1
Width of heads	6″	3″	$2\frac{1}{2}$″	$2\frac{1}{2}$″	4″	3″
" " middles	$3\frac{5}{8}$″	$3\frac{5}{8}$″	3″	3″	$2\frac{3}{4}$″	12″
Weight of heads	36·1	20·6	13·1	15·4	17·1	15·8
" " middles	24·4	23·5	17·6	20·0	20·3	74·5
" " tails	196·0	233·0	219	257·0	251·0	270·0
Total	256·5	276·1	249·7	292·4	288·4	360·3
Loss	2·5	3·9	1·3	3·6	6·6	18·0
Loss per cent	1·0	1·4	0·5	1·2	2·2	4·8

TABLE 18.

NATURAL OR MIXED FEED.

	N_1.	N_2S.	N_3S.	N_4C.	N_5C.	M.
Weight of feed in lbs.	268	230	59	245	150	244
Table inclinn.	3°10′	4°14′	......	3°36′	2°25′	....
R. P. M.	234	272	272	260	272	272
Throw	5/8″	3/4″	5/8″	3/4″	5/8″	3/4″
Feed orifice	5/16″	3/8″	1/4″	3/8″	5/16″	5/16″
Time of run	30′	14′	15½′	26′	22′	30′
Rate of feed in lbs./min.	9·0	16·4	3·8	9·4	6·8	8·2
Rate of feed in tons/24 hrs.	6·5	11·8	2·7	6·8	4·9	5·9
Feed water in lbs./min.	30·0	28·0	28·0	28·0	28·0	30·0
Wash water	52·0	...	...	...	...	
Total water	82·0	...	...	...	...	
Ratio of water to feed	9·1:1	...	...	...	...	
Width of heads	2½″	...	...	...	...	
" " middles	6½″	...	...	...	...	
Weight of heads	16·7	11·0	5·7	17·0	5·1	17·5
" " middles	39·7	42·0	11·5	53·0	19·9	48·5
" " Tails	208	174·5	41·0	170·0	119·0	171·0
Total	264·4	227·5	58·2	240·0	144·0	237·0
Loss	3·6	2·5	0·8	5·0	6·0	7·0
Loss per cent	1·3	1·1	1·3	2·0	4·0	2·9

TABLE 19.

WILFLEY TABLE TESTS—SCREENED FEEDS.

		Feed.				Heads.				Middles.				Tails.				Total.	
Test.	Mesh.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	lbs. Cu.	Wt.
S_1		430		1·51	6·50	17·4		20·81	3·62	19·4		2·07	0·40	393		0·47	1·85	5·87	430^{0}
	20	192	44·4	1·57	3·01	4·3	24·6	28·20	1·21	0·7	3·9	25·34	0·18	190^{0}	48·2	0·53	1·01	2·40	195^{0}
	30	190^{0}	44·2	1·28	2·43	6·7	38·6	28·25	1·89	8·4	43·2	2·21	0·19	172^{0}	43·8	0·37	0·64	2·72	187^{1}
	40	38^{0}	8·9			3·6	21·0	9·50	0·34	7·6	39·4	0·39	0·03	27^{0}	6·9				38^{2}
	60					2·2	12·4			2·2	11·7			3^{4}	0·8				
	100	10^{0}	2·4			0·3	2·0	2·72	0·07		1·3			1^{0}	0·2				
	—100			1·13	0·54	0·2	1·0	28·10	0·06	0·3	0·4	0·62	0·02		0·1	0·64	0·20	0·72	9·6
		430			5·99	17·3			3·57	19·2	99·9		0·42	393·4	100^{0}		1·85	5·84	429^{9}
S_2		334^{0}		2·03	6·77	16·9		28·10	4·77	22·2		3·43	0·76	295		0·39	1·14	6·67	334^{0}
	20	6^{7}	2·0				0·9				0·2			6^{3}	2^{2}				
	30	159^{0}	47·6	1·95	3·23	6·8	39·2	30·74	2·09	1·6	7·0	26·34	0·42	149^{8}	50^{8}	0·51	0·79	3·30	164^{5}
	40	103^{0}	30·8	1·99	2·05	5·0	29·7	31·40	1·57	5·1	22·9	5·21	0·26	91^{4}	31^{0}	0·28	0·25	2·08	101^{5}
	60	54^{0}	16·2			3·0	17·9	25·00	0·75	11·0	49·4	0·66	0·07	41^{8}	14^{2}				55^{3}
	100	8^{7}	2·6			1·5	9·0	10·40	0·16	3·6	16·4	0·74	0·03	4^{7}	1^{6}				9^{8}
	—100	2^{3}	0·7	2·11	1·38	0·5	3·2	20·48	0·10	0·9	4·0	3·99	0·04	1^{6}	0·3	0·14	0·07	1·22	2^{4}
		333^{7}	99·9		6·66	16·8	99·9		4·67	22·2	99·9		0·82	295	100·1		1·11	6·60	334^{0}
S_3		248^{4}		2·48	6·15	17·2		26·80	4·61	12·2		5·02	0·61	219·0		0·42	0·92	6·14	248^{4}
	20																		
	30	3^{0}	1·2			0·2	1·2			Tr.	0·2			3^{2}	1·5				3·4
	40	88·9	35·8	2·71	2·49	4·7	27·2	31·60	1·55	1·2	9·7	22·33	0·28	81^{6}	36·8	0·46	0·39	2·22	87^{5}
	60	116·2	46·8	2·34	2·72	7·1	41·2	29·72	2·11	5·2	43·1	6·20	0·32	105^{3}	48·0	0·43	0·45	2·88	117^{6}
	100	35·0	14·0			3·6	21·1	19·07	0·69	4·7	38·2	0·92	0·04	25^{9}	12·3				34^{2}
	—100	5·5	2·2	2·44	0·99	1·6	9·1	14·53	0·23	1·1	8·7	1·20	0·01	2^{8}	1·2	0·31	0·09	1·06	5^{6}
		248·6	100·0		6·20	17·2	99·8		4·58	12·2	99·9		0·65	218^{8}	99·8		0·93	6·16	248^{2}
S_4		238^{8}		2·98	7·12	21·6		28·10	6·07	14·2		3·02	0·43	203		0·38	0·76	7·26	238·8
	20																		
	30																		
	40	1^{7}	0·7			0·1	0·4			Tr.	0·1			1·5	0·7				1·6
	60	116^{2}	48·7	2·89	3·40	8·0	37·3	31·52	2·55	9·8	13·2	13·32	0·25	106·6	52·5	0·37	0·40	3·20	116·5
	100	99^{1}	41·5	2·91	2·89	9·4	43·6	29·00	2·73	9·2	64·9	2·10	0·20	81·8	40·3	0·28	0·23	3·16	100·4
	—100	21^{7}	9·1	3·75	0·81	4·1	18·7	18·37	0·75	3·1	21·9	1·01	0·03	13·0	6·3	0·34	0·04	0·8	220·2
		238^{7}	100·0		7·10	21·6	100·0		6·03	14·2	100·1		0·48	202·9	99·8		0·67	7·18	238^{7}

S_6	......	178^{3}	......	4·42	7·87	22·9	......	28·02	6·40	15·4	......	3·84	0·59	140^{0}	......	0·74	1·03	8·02	178^{3}
	20	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
	30		......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
	40	0·9	0·5			0·1	0·4			0·1	0·7			0·7	0·5				0·9
	60	3·0	1·7	3·18	0·12	0·4	1·9	27·94	0·14	0·1	0·5	4·77	0·01	2·4	1·7				2·9
	100	118·6	66·5	4·28	5·07	13·6	59·5	30·00	4·08	8·8	56·8	5·35	0·47	97·1	69·4	0·48	0·48	5·18	119^{5}
	—100	55·6	31·2	4·98	2·68	8·7	38·2	24·32	2·16	6·5	42·0	2·08	0·14	39·8	28·4	0·90	0·36	2·66	55^{0}
	......	178^{1}	99·9	.....	7·87	22·8	100·0	.....	6·38	15·5	100·0	.....	0·62	140^{0}	100·0	.....	0·84	7·84	178^{3}
S_4	......	173^{6}	......	6·27	10·83	23·6	......	27·93	6·61	58·0	......	4·45	2·58	92^{0}	......	1·83	1·68	10·87	173^{6}
	20	......	......	......	......	0·2	1·0	......	......	......	......	......	......	......	......	......	......	......	......
	30		......	......	......			......	......	......	......	......	......	......	......	......	......	......	......
	40		......	......	......			......	......	......	......	......	......	......	......	......	......	......	......
	60	1·6	0·9			0·5	2·2			0·5	0·9			0·8	0·9				2·0 2
	100	8·3	4·8	4·41	0·44	1·0	4·2	21·14	0·32	2·4	4·1	3·69	0·01	4·7	5·1	0·39	0·02	0·35	8·1
	—100	163^{5}	94·2	6·35	10·39	21·9	92·6	29·30	6·42	55·1	95·0	4·62	2·55	86·4	93·9	1·74	1·51	10·48	163^{4}
	.....	173^{4}	99·9	.....	10·83	23·6	100·0	.....	6·74	58·0	100·0	.....	2·56	91·9	99·9	.....	1·53	10·83	173^{5}

WILFLEY TABLE TESTS—CLASSIFIED FEEDS.

Test	Mesh	Feed. Wt.	Feed. % Wt.	Feed. % Cu.	Feed. lbs. Cu.	Heads. Wt.	Heads. % Wt.	Heads. % Cu.	Heads. lbs. Cu.	Middles. Wt.	Middles. % Wt.	Middles. % Cu.	Middles. lbs. Cu.	Tails. Wt.	Tails. % Wt.	Tails. % Cu.	Tails. lbs. Cu.	Total. lbs. Cu.	Total. Wt.
C_4		256^{8}	......	4·68	11·97	36^{1}	......	25·98	9·37	24·4	......	5·89	1·44	196^{0}	......	0·71	1·39	12·	20256^{8}
	20	111^{5}	43·4	2·48	2·76	4^{1}	11·3	31·11	1·26	2·2	9·0	27·88	0·61	106^{5}	54·4	0·78	0·83	2·	70112^{8}
	30	102^{3}	40·1	4·23	4·34	11^{7}	32·5	31·33	3·67	12·4	51·0	5·88	0·73	78^{3}	39·9	0·66	0·52	4·	92102^{3}
	40	26^{9}	10·5	9·25	2·49	9^{3}	25·5	24·15	2·22	6·9	28·5	1·10	0·08	9^{8}	5·0	......	......	......	25^{9}
	60	11^{8}	4·6			8^{3}	22·9	9·93	1·65	2·4	9·9			1^{2}	0·6	......	......	......	11^{9}
	100	2^{9}	1·1			2^{4}	6·4			......	0·9	......	......	......	......	......	......	......	......
	—100	0^{9}	0·3	14·93	2·32	0^{8}	1·5	20·06	0·56	0·3	0·4	0·76	0·02	0^{3}	0·1	0·58	0·06	4·	59 3^{8}
		256^{8}	100·0	..	11·91	36^{2}	100·1	...	9·36	24·2	99·7	...	1·44	196^{0}	100^{0}	...	1·41	12·	21256^{4}
C_1		276^{1}	...	2·62	7·25	20^{8}	...	25·30	5·22	23·5	......	4·08	0·96	232^{0}	......	0·49	1·14	7·	32276^{1}
	20	79^{3}	28·9	0·83	0·66	0·4	1·8	33·02	0·13	0·3	1·2	25·20	0·08	80^{3}	34·6	0·38	0·32	0·	53 81^{0}
	30	120^{3}	43·5	1·44	1·73	2·7	13·0	32·24	0·87	4·9	20·9	10·41	0·51	115^{1}	49·6	0·54	0·62	2·	00122^{7}
	40	42^{8}	15·5	3·73	1·60	4·8	23·1	29·80	1·43	9·7	41·5	2·62	0·25	29^{1}	12·6	0·38	0·10	1·	78 43^{6}
	60	25^{1}	9·1	8·79	2·20	8·2	39·9	23·27	1·90	7·3	31·2	0·74	0·05	6^{8}	2·9	......	......	......	22^{3}
	100	6^{8}	2·4		.	3·8	18·5	22·15	0·84	1·1	4·6			0^{8}	0·3	0·50	0·04	3·	00 5^{8}
	—100	1^{4}	0·5	14·75	1·21	0·8	3·7	20·05	0·16	0·1	0·5	0·72	0·01	Tr.	......	......	......	......	0·9
		275^{9}	99·9	..	7·40	20·7	100·0	...	5·33	23·4	99·9	...	·90	231^{9}	100^{0}	.....	1·08	7·	31276^{0}

TABLE 19—(Continued).

Test	Mesh	Feed Wt.	Feed % Wt.	Feed % Cu.	Feed lbs. Cu.	Heads Wt.	Heads % Wt.	Heads % Cu.	Heads lbs. Cu.	Middles Wt.	Middles % Wt.	Middles % Cu.	Middles lbs. Cu.	Tails Wt.	Tails % Wt.	Tails % Cu.	Tails lbs. Cu.	Total lbs. Cu.	Total Wt.
C_3	...	249^7	...	2·03	5·02	13·1	...	27·03	3·57	17·6	...	2·51	0·85	219^0	...	0·41	0·90	5·32	249^7
	20	32^8	13·1	0·30	0·10	Tr.	0·2	...	...	Tr.	0·1	...	...	33^6	15·5	0·30	0·10	...	33^6
	30	105^9	42·4	0·72	0·76	0·2	1·8	33·00	0·08	0·6	3·6	18·10	0·11	106^0	48·4	0·50	0·53	0·82	106^8
	40	53^9	21·6	0·61	0·87	1·0	7·5	31·85	0·32	4·4	25·2	7·61	0·34	49^3	22·5	0·43	0·21	0·87	54^7
	60	38^9	15·2	4·82	1·87	4·6	35·5	27·30	1·25	8·7	49·5	3·78	0·33	25^7	11·4	...	...	...	39^0
	100	15^2	6·1	...	...	5·5	41·9	25·75	1·42	3·3	18·9	2·06	0·07	4^2	1·9	...	...	...	13^0
	—100	3^5	1·4	12·90	2·41	1·7	12·9	24·11	0·41	0·5	2·7	1·70	0·01	0^4	0·2	0·33	0·10	3·59	2^6
		250^0	99·8	...	5·91	13·0	99·8	...	3·48	17·5	100·0	...	0·86	219^3	99·9	...	0·94	5·28	249^7
C_4	...	292^0	...	1·88	5·50	15·4	...	26·50	4·07	20·0	...	4·44	0·88	257^0	...	0·34	0·87	5·82	292^4
	20	7^0	2·4	0·18	0·01	...	...	...	...	Tr.	0·1	...	...	7^5	2·9	0·21	0·02	...	7^5
	30	72^0	24·6	0·35	0·25	Tr.	0·1	...	...	0·1	0·5	...	...	78^2	30·4	0·23	0·18	...	78^3
	40	77^4	26·5	0·29	0·22	0·2	1·1	27·70	0·06	1·0	5·0	5·68	0·06	75^9	29·5	0·41	0·31	0·63	77^1
	60	81^2	27·8	1·32	1·08	2·3	15·0	30·20	0·66	7·9	39·7	5·44	0·43	70^6	27·4	0·40	0·28	1·37	80^7
	100	40^9	14·0	6·67	2·72	8·1	52·4	27·91	2·26	8·7	43·8	4·03	0·35	21^7	8·5	...	...	...	38^5
	—100	13^4	4·6	13·55	1·80	4·8	31·4	25·53	1·19	2·3	11·4	2·61	0·06	3^1	1·2	0·52	0·13	3·99	10^2
	...	291^9	99·9	...	6·08	15·4	100·0	...	4·17	20·0	100·5	...	0·90	256^9	99·9	...	0·92	5·99	292^3
C_5	...	288^0	...	2·13	6·14	17·0	...	25·69	4·38	20·3	...	3·71	0·75	251^0	...	0·38	0·96	6·09	288^3
	20	0^4	0·2	...	...	Tr.	0·1	...	...	Tr.	0·1	...	...	0^5	0·2	...	...	...	0^5
	30	11^1	3·8	0·52	0·01	0·1	0·4	...	...	0·1	0·7	...	...	10^0	4·2	0·14	0·01	...	10^2
	40	39^3	13·7	0·17	0·07	0·1	0·4	...	...	0·2	1·0	0·73	Tr.	39^3	15·6	0·24	0·09	...	39^6
	60	100^0	34·7	0·30	0·30	0·6	3·2	15·89	0·11	2·0	10·0	2·16	0·05	98^0	38·9	0·21	0·21	0·47	100^6
	100	87^0	30·2	2·03	1·76	4·9	28·9	28·29	1·39	9·7	47·7	4·03	0·39	73^6	29·2	0·35	0·26	2·04	88^2
	—100	50^5	17·5	7·80	3·94	11·4	66·9	25·02	2·85	8·3	40·7	4·23	0·35	29^9	11·9	0·97	0·29	3·49	49^6
	...	288^3	100·1	...	6·08	17·1	99·9	...	4·35	20·3	100·2	...	0·79	251^3	100·0	...	0·86	6·00	288^7
C_6	...	360	...	2·22	8·01	15·8	...	26·76	4·21	74·5	...	2·551	·90	270^0	...	0·701	·89	8·003	60^0
	20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	30	0^9	0·2	...	...	0·3	1·5	0·73	Tr.	0·1	0·2	...	...	0^7	0·3	...	...	...	1^1
	40	4^9	1·3	...	...	0·2	1·4	2·10	Tr.	0·4	0·6	...	...	4·0	1·5	...	...	...	4^6
	60	44^1	12·3	0·24	0·11	0·5	2·9	6·23	0·03	3·3	4·4	0·25	0·01	36^2	13·4	0·09	Tr.	0·04	40^0
	100	133^0	36·9	0·62	0·82	2·3	13·5	23·74	0·55	28·4	38·2	0·72	0·20	104^0	38·6	0·18	0·19	0·94	134^7
	—100	177^0	49·3	3·97	7·02	12·6	80·5	28·97	3·65	42·3	56·6	3·86	1·63	125^0	46·2	1·37	1·71	6·99	179^9
	...	359^9	100·0	...	7·95	15·9	99·8	...	4·23	74·5	100·0	...	1·84	269^9	100·0	...	1·90	7·97	360^3

WILFLEY TABLE TEST—NATURAL FEED.—(DESLIMED).

		Feed.				Heads.				Middles.				Tails.				Total.	
Test.	Mesh.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	Wt.	% Wt.	% Cu.	lbs. Cu.	lbs. Cu.	Wt.
N_1	....	264^4	....	2·57	6·80	16·7	....	28·91	4·83	39·7	....	2·95	1·17	208	....	0·52	1·08	7·08	264^4
	20	37^5	14·2	1·67	0·63	1·2	7·3	30·00	0·36	1·8	4·5	3·20	0·06	33^9	16·3	0·58	0·20	0·64	36^9
	30	69^0	26·1	1·93	1·33	3·1	18·7	31·21	0·97	3·6	9·0	3·01	0·11	61^3	29·5	0·48	0·30	1·38	68^0
	40	48^4	18·3	2·61	1·22	2·9	17·3	31·74	0·92	5·8	14·7	2·30	0·13	39^3	18·9	0·26	0·10	1·15	48^0
	60	46^0	17·4	2·55	1·17	2·6	15·6	29·13	0·76	9·0	22·6	2·19	0·20	33^9	16·3	0·40	0·13	1·09	45^5
	100	33^8	12·8	3·07	1·04	3·8	23·0	26·60	1·01	10·4	26·3	2·13	0·22	22^2	10·7	0·35	0·08	1·31	36^4
	—100	30^1	11·4	4·62	1·39	3·0	17·8	26·48	0·79	9·1	23·0	4·88	0·44	17^3	8·3	1·09	0·19	1·42	29^4
	....	264^5	100^2	.....	6·78	16·6	99·7	.....	4·81	39·7	100·1	.....	1·16	207^9	100..	....	1·00	6·97	264^2

TABLE 20.

RECOVERY—PRIMARY.

Run.	Size.	Feed comp. % cu.	Percentage of Products.			Per Cent of Total Copper.			Heads and middles % total copper.
			Heads.	Middles.	Tails.	Heads.	Middles.	Tails.	
N_1	Mesh Th. 18	2·57	6·3	15·0	78·7	69·1	16·6	14·3	85·7
S_1	On 20	1·51	4·1	4·5	91·4	61·7	6·8	31·5	68·5
S_2	30	2·03	5·1	6·6	88·3	71·5	11·4	17·1	82·9
S_3	40	2·48	6·9	4·9	88·2	75·1	9·9	15·0	85·0
S_4	60	2·98	9·1	6·0	84·9	83·6	5·9	10·5	89·5
S_5	100	4·42	12·9	6·6	78·5	81·4	7·9	10·7	89·3
S_6	—100	6·27	13·6	33·4	53·0	62·3	23·6	14·1	85·9
C_1	Coarse	4·68	14·1	9·5	76·4	76·8	11·8	11·4	88·6
C_2	....	2·62	7·5	8·5	84·0	73·0	12·3	14·7	85·3
C_3	....	2·03	5·3	7·0	87·7	67·0	16·0	17·0	83·0
C_4	....	1·88	5·3	6·8	87·9	69·9	15·1	15·0	85·0
C_5	....	2·13	5·9	7·0	87·1	72·0	12·3	15·7	84·3
C_6	Fine	3·22	4·4	20·7	74·9	52·6	23·7	23·7	76·3

TABLE 21.

Recovery—Secondary—Screened Feed.

(Per Cent Copper in Heads, Middles and Tails in Various Sizes.)

Size.	S_1H	S_1M	S_1T	S_1F	S_2H	S_2M	S_2T	S_2F	S_3H	S_3M	S_3T	S_3F
20	50·4	7·5	42·1	100·0								
					63·4	12·7	23·9	100·0				
30	69·5	7·0	23·5	100·0								
									69·8	12·6	17·6	100·0
40					75·5	12·5	12·0	100·0				
60									73·2	11·11	5·7	100·0
	65·2	7·0	27·8	100·0								
100					82·7	11·5	5·8	100·0				
									86·8	4·7	8·0	5,100·0
—100												

Size.	S_4H	S_4M	S_4T	S_4F	S_5H	S_5M	S_5T	S_5F	S_6H	S_6M	S_6T	S_6F
20												
30												
40	79·7	7·8	12·5	100·0								
									91·5	2·8	5·7	100·0
60					81·4	9·3	9·3	100·0				
100	86·4	6·3	7·3	100·0								
—100	91·4	3·7	4·9	100·0	81·2	5·3	13·5	100·0	61·3	24·3	14·4	100·0

TABLE 22.

RECOVERY—SECONDARY—CLASSIFIED FEED.

(Per Cent Copper in Heads, Middles and Tails in Various Sizes.)

Size.	C_1H	C_1M	C_1T	C_1F	C_2H	C_2M	C_2T	C_2F	C_3H	C_3M	C_3T	C_3F
20	46·6	22·6	30·8	100·0	24·5	15·1	60·4	100·0	9·8	13·4	76·8	100·0
30	74·6	14·8	10·6	100·0	43·6	25·4	31·0	100·0				
40					80·3	14·1	5·6	100·0	36·8	39·1	24·1	100·0
60 / 100	96·5	2·2	1·3	100·0	96·8	2·0	1·2	100·0	85·8	11·4	2·8	100·0
—100												

Size.	C_4H	C_4M	C_4T	C_4F	C_5H	C_5M	C_5T	C_5F	C_5H	C_6M	C_6T	C_6F
20												
30	9·5	9·5	81·0	100·0								
40					23·4	10·6	66·0	100·0	75·0	25·0	0·0	100·0
60	21·0	31·8	47·2	100·0								
100					68·2	19·1	12·7	100·0	58·5	21·3	20·2	100·0
—100	86·6	10·1	3·3	100·0	81·7	10·0	8·3	100·0	52·3	23·3	24·5	100·0

TABLE 23.

RECOVERY—SECONDARY—NATURAL FEED.

(Per Cent. Copper in Heads, Middles and Tails on Various Sizes.)

Size.	N_1H	N_1M	N_1T	N_1F
20	56·3	9·4	31·3	100·0
30	70·3	8·0	21·7	100·0
40	80·0	11·3	8·7	100·0
60	69·8	18·3	11·9	100·0
100	77·1	16·8	6·1	100·0
—100	53·6	31·0	13·4	100·0

TABLE 24.

SCREEN ANALYSES OF ORIGINAL FEED.

		Sample A.		Sample B.		Mean.	
Mesh.		Wgt.	% Wgt.	Wgt.	% Wgt.	% Wgt.	% Cu.
		150 0 gms.	100·0	150·0 gms.	100·0	100·0	2·42
On	20	20·0	13·3	20·0	13·3	13·3	1·27
	30	39·2	26·2	39·0	26·0	26·1	1·73
	40	22·5	15·0	22·4	14·9	15·0	1·84
	60	25·3	16·9	25·3	16·9	16·9	2·49
	100	22·0	14·7	22·3	14·9	14·8	2·47
	—100	20·8	13·9	20·8	13·9	13·9	5·15
		149·8	100·0	149·8	99·9	100·0	

TABLE 25.

SCREEN ANALYSES.

		Original Feed.		Screened Ore.		Classified Ore.	
Mesh.		% Wgt.	% Cu.	Wgt.	lbs. Cu.	Wgt.	lbs. Cu.
		100·0	2·42	185·0	44·75	185·5	44·90
On	20	13·3	1·27	24·6	3·12	24·7	3·14
	30	26·1	1·73	48·4	8·38	48·5	8·40
	40	15·0	1·84	27·8	5·11	27·9	5·14
	60	16·9	2·49	31·3	7·80	31·4	7·83
	100	14·8	2·47	27·4	6·76	27·5	6·79
	—100	13·9	5·15	25·7	13·25	25·8	13·30
Totals		100·0	...	185·2	44·42	185·8	44·60

TABLE 26.

ADDITIONAL SCREEN ANALYSES.

Mesh.	S_6 Feed % Wgt.	S_6 Heads % Wgt.	C_6 Feed % Wgt.	C_6 Heads % Wgt.	N_1 Feed % Wgt.	N_1 Heads % Wgt.
On 120........	16·6	15·4	60·0	27·5	90·0	85·0
200........	43·0	39·9	20·0	29·5	6·0	9·8
—200........	38·4	44·7	20·0	43·0	4·0	5·2
Totals....	100·0	100·0	100·0	100·0	100·0	100·0

TABLE 27.

ADDITIONAL RECOVERIES.

(Total lbs. Copper.)

Screened Feed. Heads.	Middles.	Feed.	Classified Feed. Heads.	Middles.	Feed.
Including run S_6.			Including C_6.		
32·12	5·57	44·55	30·93	6·80	44·74
72·1%	12·5%	....	69·1%	15·2%	....
Neglecting S_6.			Neglecting C_6.		
25·38	2.99	33·72	26·72	4·90	36·74
75·3%	8·9%	....	72·8%	10·9%	....
Increased Recovery.			Increased Recovery.		
3·2%	— 3·6%		3·7%	— 4·3%	

DISCUSSION OF THE RESULTS OBTAINED.

From Tables 16, 17, and 18 we find the capacity of the experimental table used to be about twelve tons per 24 hours with the coarse feed, for either screened or classified material, with the advantage in favour of the former. On very fine feed the capacity falls as low as 2·2 tons in 24 hours with screened feed, and 3·6 tons for classified feed, the over all average being about 8·0 tons.

The Wilfley table has a capacity of from, say, 20 to 30 tons on the average coarse ore, which can sometimes be pushed, in very favourable conditions, up to 40 tons per 24 hours; while for finer feed its capacity ranges down to 10 tons per 24 hours, or an average for all sizes in their proper proportions of, say, 18 tons.

Prof. Richards, in deciding upon the proper rate of feed for his small table, assumed that the capacity of a table is directly proportional to its area. This may be true of tables not differing very greatly in size, but it is scarcely likely to be true as regards tables differing so greatly as his 2′ x 4′ apparatus and the standard Wilfley. It would seem more likely that the capacity would vary according to the portion of the table actually covered by the ore stream, or, in other words, by a somewhat narrow band following the diagonal. This seems to be borne out by the result of the tests above recorded. The area of a standard table is, roughly, 95 sq. ft., and its diagonal about 17 ft.; while the area and diagonal of the experimental table used in our tests were 22 sq. ft. and 7·7 ft. The average capacity of a standard Wilfley may be taken at, say, 18 tons per 24 hours, and the tables show that the McGill table had a capacity of about 8 tons. The ratio of diagonals=7·7 to 17=$\frac{1}{2.21}$, and the ratio of feeds 8 to 18=$\frac{1}{2.25}$.

Tables 16, 17, and 18 give complete and detailed analyses of the Wilfley runs on the screened, classified and natural feeds respectively. Nowhere in Prof. Richards' discussion was the writer able to find any data as to the slope, feed water, wash water, throw and the like, so a comparison is impossible.

It should be noted in connection with Table 16 that the ore was first screened through the 100 mesh Callow screen (run S_6); then passed over the 60 mesh screen (run S_5) et cetera. Thus run S_1 should contain only material coarser then 20 mesh, run S_2 only material through 20 mesh but on 30 mesh and so on.

The runs in Table 17 graduate from coarse material to fine;—run C_1 being the spigot product from classification run No. 2 (table 11), and C_6, containing the finest product of all, being the overflow of classification run No. 1 (Table 11). C_5 is the next finest run and is the overflow of classification run No. 5; C_4 is the spigot product of classification run No. 5; C_3 the spigot of run No. 4 and C_2 the spigot of run No. 3.

It will be noticed that, in these tests also, the rate of feed diminishes with the decrease in size of the feed particles. The ratio of the total water to the feed rate increases steadily but shows a very large jump in the finest run, being about 30 to 1 in S_6 and C_6.

In the screened feeds the width of the heads band steadily increases, showing the greatest quantity of copper in the finest run. The classified feed tests show the widest band of mineral in run C_1. This run also produces nearly one-third of the total amount of heads.

Table 19 shows a complete yet comprehensive summary of the results obtained in the tests; it gives the screen analyses and the assay values in percent. and also pounds of copper in the feed, heads, middles and tails.

An examination of this table will show the exceptional accuracy of the screen analyses. This is due to the efficiency of the screening machine, which is described in detail in Appendix I. With very fine material, however, the sieves clogged and in the screened feed tests, all the screening had to be finished by hand because of the great concentration of the material.

All of the assays were done by the cyanide method which is described in detail in Appendix II. Including checks, about 500 determination were made in all.

Referring again to Table 19, we find that in every case the primary assay of the heads, middles and tails check, sometimes exactly but invariably within very small limits. Thus in S_1 we get the total pounds of copper in the heads, middles and tails to be 5·87. On addition of the amounts of copper on the various sizes in the heads, middles and tails we have 5·84 pounds.

S_4 shows 7·26 pounds of copper in the total of the primary assays, whereas the secondary assays add up to 7·18. The difference is very small, yet an explanation can be given for it. We notice in the tails of S_4 that the primary assay shows C·76 lbs. of copper, and the secondary assays only 0·67. It seems obvious that the primary assay is wrong, inasmuch as the secondary assays were checked.

The majority of the feed assays check excellently with their respective heads, middles and tails; but three or four have evidently become accidentally salted, no doubt in the sampling or grinding, as in some cases, work on high grade ore was proceeding nearby at the same time. This has been the case with S_1 feed, with C_1 feed to a much less extent, with C_3 and with the primary assay of C_4. These errors or discrepancies are to be regretted; but they are very few in view of the large number of samples assayed, and on the whole the results of the sampling, screening, and assaying are very satisfactory.

It will be noticed in the case of the screened feed runs, that the amount of copper in the feed steadily increases, on the whole, with the increased fineness of the feed, notwithstanding the fact that the amount of the feed steadily decreases the while from 430 lbs. in S_1 to 173·6 lbs. in S_6.

The feed in S_1 is considerably over twice the amount of the feed to run S_6 and yet the copper in S_1 is little more than half the weight of the copper in S_6.

The feed to S_6 is a trifle less in quantity than the feed to S_5, yet the amount of copper is nearly 3 pounds more, showing a great increase in richness.

Correspondingly we find a generally increasing amount of copper saved in the heads but by no means so great an increase as the increase of copper in the feed.

The amount of copper saved in the middles remain more or less constant, except for S_6 in which run the copper rises from about 0·6 lbs. to over 2½ lbs.

The tailings show a steady decrease in the copper contents till test S_5, whereat it starts to rise again, test S_5 showing a decided increase over S_4, while the copper in the tailings of S_6 is nearly three times that contained in S_4 and almost twice the amount given for S_5.

Turning to the classified feeds, we have an entirely different state of affairs. The amount of copper in test C_1 is much greater than in any of the other tests, though in amount of ore feed it is one of the smallest. In C_2 the copper in the feed decreases from about the 12·2 of C_1 to about 7·3 lbs. Test C_3 contains the least amount of copper but C_4 shows the lowest percentage of copper in the feed. C_6 is a little richer than C_5 but it is nearly 100 lbs. greater in quantity and hence has about 2 lbs. more copper.

The copper saved in the heads reaches a maximum in C_1, drops suddenly in C_2, thence slowly to C_4 then it takes an upward turn to C_6 which shows a slight decrease.

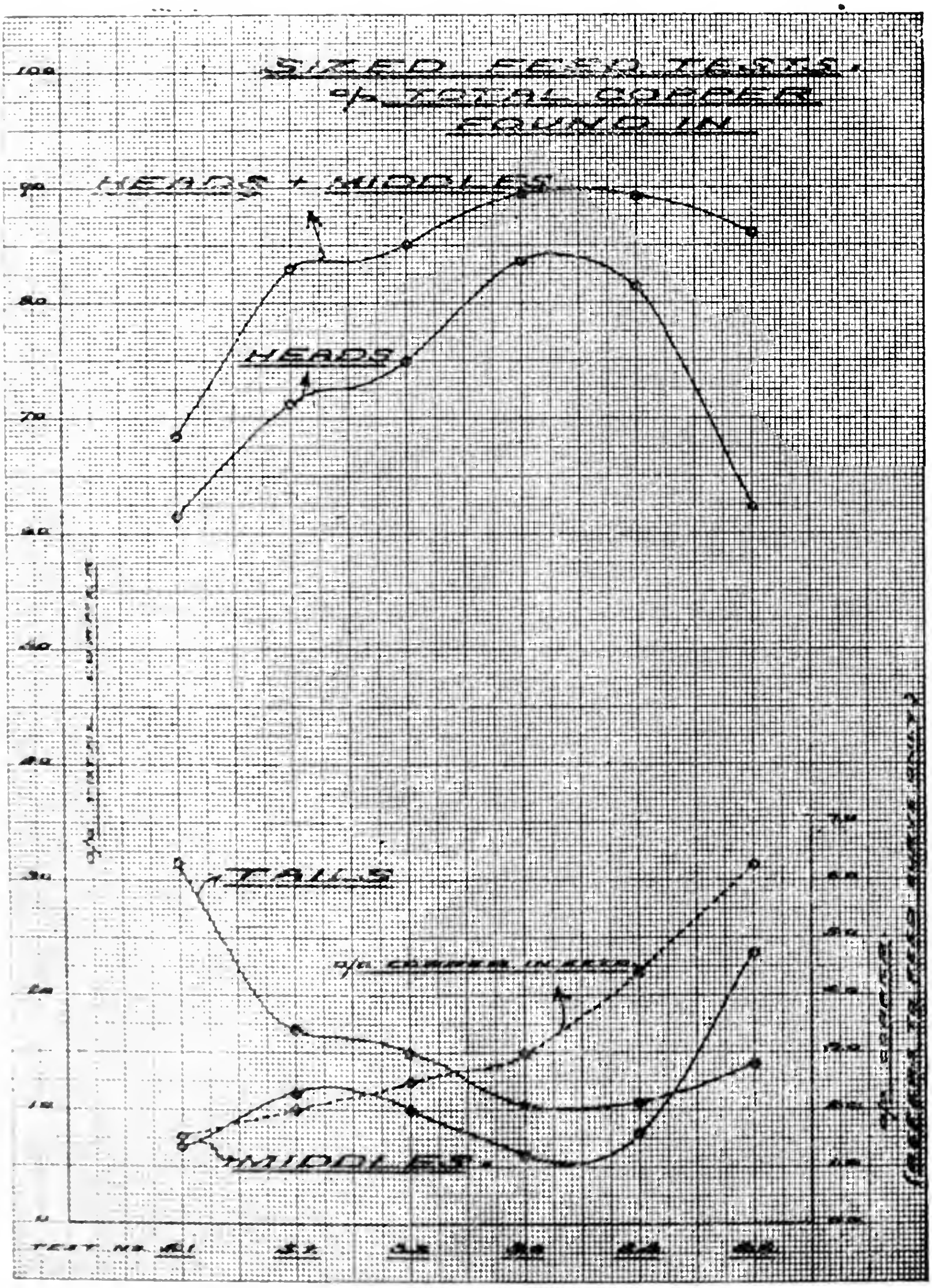
The copper content of the middles product shows a steady decrease from 1·44 lbs. in C_1 to 0·75 lbs in C_5; in C_6 it jumps up to 1·9 lbs.

The tailings give a decreasing amount of copper from 1·39 lbs. in C_1 to 0·87 lbs. in C_4; C_5 tailings are richer while in C_6 the copper in the tailings is more than doubled.

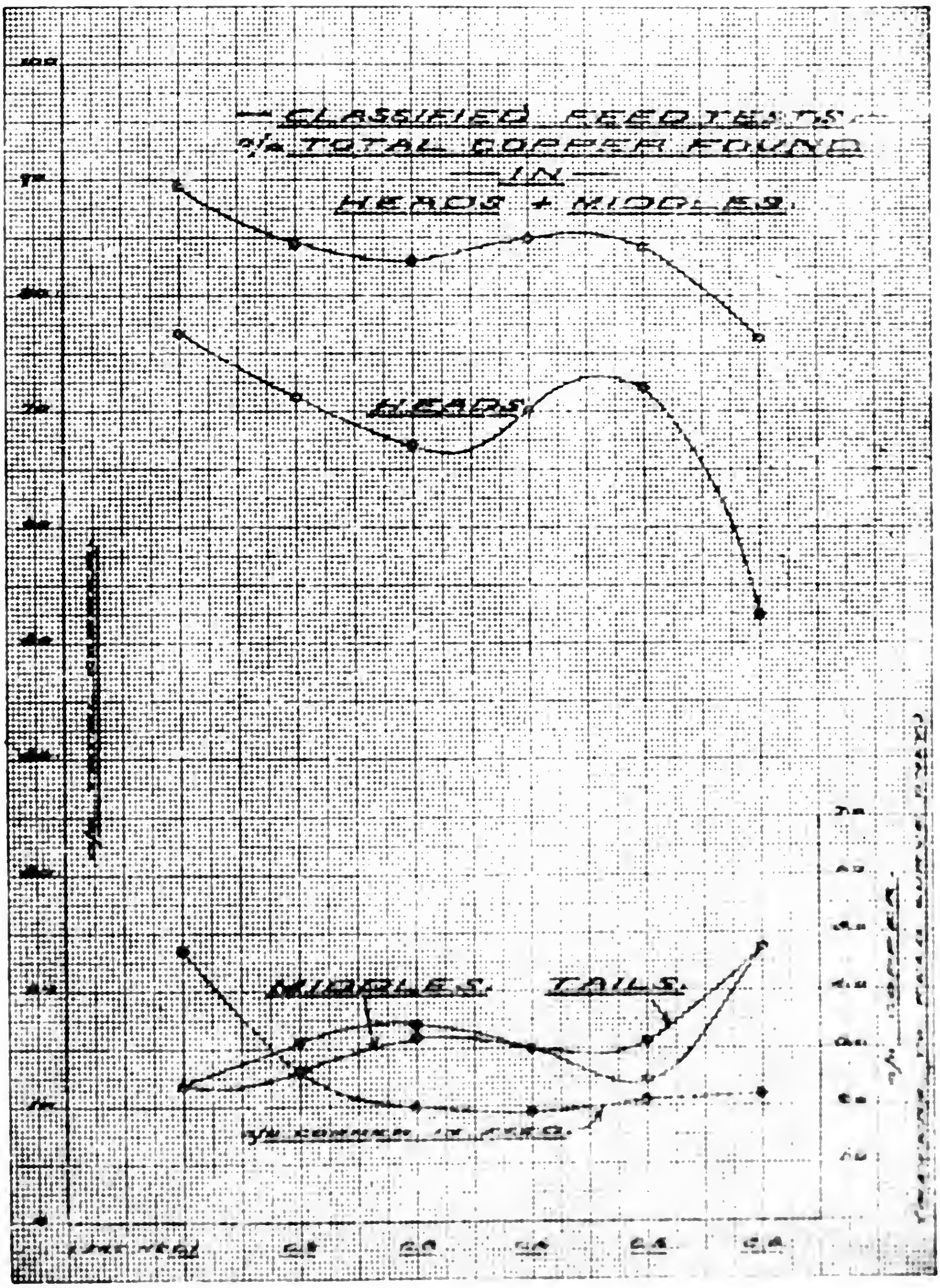
The heads of the C tests are in no case as rich as the richer of the S tests, but, on the other hand, no C test falls as low as S_1.

The heads obtained in the natural feed, sun N_1, are the richest of the tests.

The accompanying curves illustrate these facts graphically. In the heads diagram we see the remarkable similarity of the

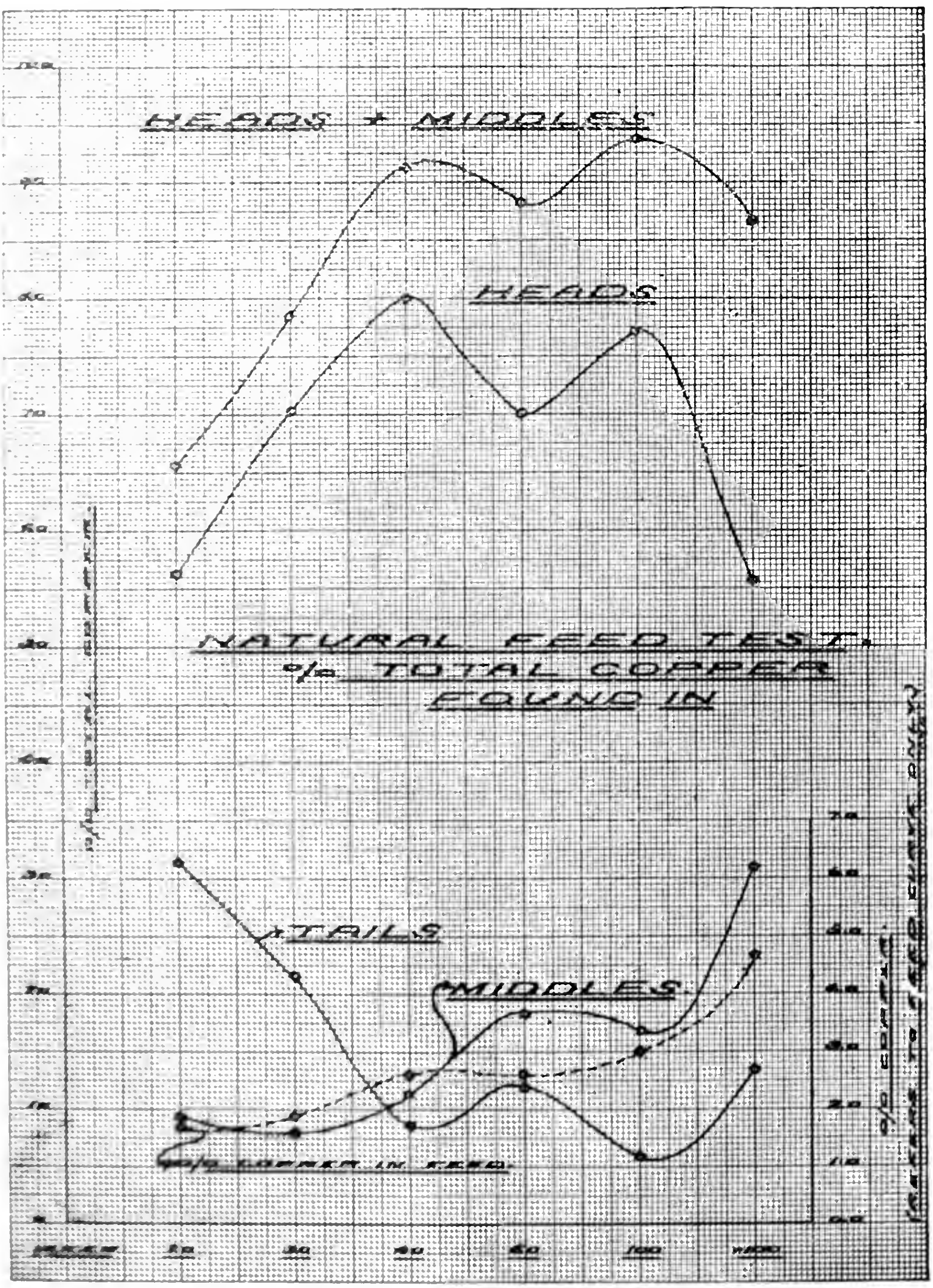


recovery in the finer sizes. As the dotted lines show, had not the recovery in the natural feed on the 60 mesh fallen, the curve would have been very similar to the screened feed curve, and even more regular. From our original feed analyses and assays, table 24, one would expect the recovery to follow the dotted lines and it is quite possible that the result obtained by us was a mere coincidence.



The middles recoveries of screened and natural feeds show the same general trend, curves somewhat comparable to the letter S. The natural feed, however, is a curve comparable to a rectangular hyperbola.

The combined recovery curves prove the natural feed to be clearly superior to the others, especially if the curves are rounded out as shown.



The screened feed curve is similar in shape to the natural feed curve. The classified feed curve has the appearance of a switchback, the recovery rising and falling, though always showing a general decrease.

Table 24 gives the results obtained in screening two absolutely independent samples of the feed; it is an interesting illustration of the efficiency of the screening machine. The table also shows the percentage of copper in the various sizes.

Table 25 gives the amounts of copper in the various sizes of the original feed as used for the screening tests and for the classification tests. It will be seen that the primary and secondary assays check exceedingly well, showing a difference of only 0·3 lbs. of copper, or less than 0·7%.

These tables agree very fairly with Table 19. Thus, from Table 19 C tests, We find about 3·3 lbs. of copper ore on 20 mesh. Table 25 shows 3·14 lbs. In the finest test, C_6, we got about 13 lbs. from Table 19 as against 13·5 lbs. from Table 25.

The total amount of copper in the classified feed tests adds up to about 44·7 lbs. as against a feed of 44·9 in Table 25; a loss of 0·2 lbs., and this loss may be hypothetical as a very slight error in sampling or analyses would cancel it. Similarly, the total copper in the screened feeds comes to about the same amount. These checks are important as affording proof of the substantial accuracy of the tests and their tabulation.

Table 20 illustrates several interesting points. Firstly, the classified feed shows its best recovery in coarse run, C_1. This run also has by far the greatest peroentage of heads. The worst results are found in the finest run, C_6, which run shows the smallest percentage of heads.

In the screened feed, we have exactly the reverse in almost every detail. The amount or rather the percentage of heads in S_1 and S_6 correspond very closely to that found in C_6 and C_1 respectively, though the recovery in S_1 is 10% better than the recovery of C_6, being 61·7% as compared to 52·6%.

But S_6 shows a recovery of only 0·6% above S_1. The best recovery in the screened tests is found in S_4 and S_5. The screened feed tests are the only ones to give a recovery of over 80%, and the average recovery of the screened feed is higher than the classified feed. From Table 27 we find that the total average recovery in the screened feed tests is 72·1% as against 69·1% for the classified feed. The latter recovery is, oddly enough, the same as is obtained in the natural feed run, N_1 (Table 18). If we consider the combined recovery of the heads and middles, the same general results are noticed. The combined recovery of the screened feed tests is 85·6%; of the classified feed tests 84·3%; of the natural feed 85·7%. The three series are now nearly equal, with the advantage in favour of the natural feed; the classified feed is a little below the others.

As the feed for S_6 and C_6 was thought to be rather finer than is usual for Wilfley table treatment, we decided to make a few additional screen analyses to find out the composition of these runs. Table 26 shows the results. We notice that the feed and heads of S_6 are comparable but that the heads of C_6 are composed of much finer material than the average feed. The natural feed and heads show little variation. These results proved, however, that the mineral in runs S_6 and C_6 was very fine and liable to loss when treated on the Wilfley Table. It was determined to estimate the recovery neglecting these runs. Table 27 illustrates this point. We notice that the recovery in the heads rises in either case over 3·0%. The combined recovery of heads and middles is rather less.

However, the losses in the tailings of these two runs are very considerable, especially in the case of C_6, and it is probable that the Frue Vanner could be used to advantage on this material.

From Table 26 it will be seen that the percentage of fines in the natural feed is comparatively small, both in the general feed and in the heads. It occurs to the writer that perhaps this is the explanation of the favourable results of the natural feed run. The small percentage of fine mineral is trapped to a considerable extent by the coarser mineral. It is probable that the natural feed run could be made to give a much better combined recovery by making more middles. Had the middles band been about 10″ wide instead of 6½″, the writer believes the mineral lost in the tailings would have been considerably reduced.

Tables 21, 22 and 23 give the percentage recoveries in the heads, middles and tails of the secondary assays of the screened feed tests, the classified feed tests and the natural feed tests respectively.

Referring to Table 21, it will be observed that in general the recovery rises with the increased fineness of the feed until test S_5. In this run the recovery drops to 81·2% with a further decrease to 61·3% in S_6.

Table 22 exhibits a marked divergence from Table 21. The recovery on the coarser sizes decreases from 46·6% in C_1 to 9·8% in C_3 heads. The heads show the greatest recovery in the fines of C_1 and steadily decrease, C_6 marking a drop of nearly 30% from C_5.

Table 23 points out that in the natural feed, the recovery is best in the medium sized material. As before mentioned, the comparatively poor recovery in the 60 mesh may be due to some unknown error.

CONCLUSIONS.

From the foregoing results, it is scarcely possible to avoid the conclusion that classified feed is apparently less satisfactory than screened feed.

Screened feed shows the best recovery in the heads, and if the last run is omitted, gives a really good total recovery of 75·3%. This is 6·2% higher than the recovery on the natural feed or classified feed products, and it is probable that this increased recovery would repay the extra cost of treatment; the same conclusion holds as regards natural feed, except that it is scarcely safe to put too much trust in one trial, no matter how well it works out.

It is far from the writers' wish to appear dogmatic. They realize fully that the matters here considered are too extensive and complicated to be conclusively determined in any single series of tests; but they hope that their work will have some value, and will play its part in the settlement of a question of great interest to both students and practitioners of the art of ore dressing.

APPENDIX I.

SCREEN ANALYSES.

The screen analyses of the various samples were done almost entirely by machine. This machine which was built on lines suggested by that described by T. J. Hoover* consists essentially of a vertical shaft driven by bevel gears from a horizontal shaft connected by belting to one of the regular line shafts in the laboratory. The vertical shaft has a horizontal plate on its upper end, supporting from an eccentrically placed pin, a reck for holding the screens. This rack will hold any number of screens from one up to over a dozen nested together. The pin has an eccentricity of 1½ inches and the shaft revolves about 180 R.P.M., so that the screens get a rapid gyratory motion which while rapidly separating the undersize from the oversize does not tend to blind the screens badly. For these analyses fine screens were used—20, 30, 40, 60 and 100 mesh I.M.M. standard. It was found that with a 200 gram sample, 35 minutes was sufficient to give practically perfect screening. In a few cases only with the screen sized sands, where one screen held the major portion of the sample, was it necessary to finish off the work of the machine by hand.

The excellent work of this machine is well shown in Table 17, by a comparison of the third column on the left with the last column on the right. (The latter giving the addition of the quantities in the various sizes of the H.M. and Tails.)

APPENDIX II.

The following details of the method used for assaying the samples may be of interest. Samples of all products were taken in duplicate—5 grammes in the case of ore samples for the trials; 2 grammes for feed samples, and 1 gramme for heads and middles. These samples were all ground to pass through 100 mesh, and were then taken to the chemical laboratory.

The weighed ore was placed in a casserole and to it was added 10 c.c. of strong nitric acid and 5 c.c. of strong hydrochloric acid. It was then evaporated to dryness; 5 c.c. of hydrochloric acid and 10 c.c. of sulphuric acid were added and evaporated to copious fumes of sulphur trioxide to ensure the driving off of the last traces of nitric acid and the hydrochloric acids. Water was added and a piece or two of aluminium foil, with one drop of hydrochloric to start the action. This was boiled till all the copper had come down, whereupon it was decanted through a filter and carefully

*Transactions—Institution of Mining and Metallurgy. Vol. xix, p. 504.

washed three times with hot water. Ten c.c. of nitric acid were added; the aluminium foil taken out and washed and the copper nitrate solution poured through the filter, washed three times and the filtrate diluted to the same amount each time. Then 20 c.c. strong ammonia water were added and the solution titrated by the standardized cyanide solution till colourless.

This solution was prepared by dissolving about 30 grammes of potassium cyanide in about 3 litres of distilled water.

One gramme of pure copper foil was dissolved in 10 c.c. nitric acid and diluted to exactly 500 c.c. By means of a pipette exactly 50 c.c. were withdrawn. This amount of the solution thus contained 0·1 gms. of copper.

This solution was diluted to the same mark as the others; 20 c.c. of ammonia added and titrated with the potassium cyanide solution. Dividing 0·1 by the number of cubic centimetres of solution used to decolarize the solution, gave the value of the standard solution in terms of copper. This value was generally about ·0021. Thus 1 c.c. KCN neutralized ·0021 gms. of copper.

Great care was taken to have precisely similar conditions in all cases. In order to eliminate the personal equation as far as possible, all titrations and standardizations were done by one man—Mr. J. R. Cox.

In this manner we found it possible to sample, grind, weigh and assay from 20 to 30 samples per day.

PHOTOGRAPHY FOR MINING ENGINEERS AND GEOLOGISTS.

By H. MORTIMER-LAMB, Montreal.

(Annual Meeting, Quebec, 1911.)

There are few more popular hobbies than photography. Its practice is now universal. That it should continue to be so is surprising in that the results obtained by the large majority of camera users are utterly abominable. It is, perhaps, because photography has come to be regarded as a sort of popular pastime that its value and capabilities are so lightly regarded or so imperfectly realized by practical men. The improvements in dry plates and apparatus in the past few years, the very ease with which results of sorts are secured, are also in part responsible for careless manipulation and slip-shod methods of working. So far as this applies only to the ordinary amateur muddler it is of small concern; but when we come to the application of photography to professional or scientific uses, it is essential, of course, that the work should be done with the same care and attention as would have to be observed in the conduct of any operation the success of which is dependent on scientific accuracy and manipulative dexterity.

It were superfluous to dwell on the common advantages of graphic representation as a means of expressing ideas. These have been recognized from the earliest times; but until the discovery of photography absolute veracity or exact precision of expression was not possible,—that is to say when dealing with concrete facts and not abstractions. Consequently, in a profession such as mining, where ambiguity is a cardinal sin, photography can and should serve a particularly useful function, and is most worthy of domestication. The force of this contention was first brought home to the writer some years ago. A certain important power installation was being made near Vancouver, in British Columbia. The directors of the Company expressed a desire to be advised daily of progress. The engineer in charge, an extraordinarily capable man, yet like many another not notably partial to or dexterous in the matter of report-making, decided that all ends would be served by means photographic, and so for several weeks from the commencement of operations until the completion of the work, every day from six to a dozen plates would be regularly exposed and developed, prints made from the wet negatives, and within twelve hours these records, neatly pasted in little booklets of grey paper, would be in the hands of the several directors. The photographs not only saved folios of written information and explanation, but gave that information and explanation much more decisively and clearly than was possible by other means. Nor was their value transitory, for they continue to be treasured as a complete and perfect historical record of the initiation of the Company's enterprise.

Again, only recently the writer was shown a report prepared by one of our best known consulting geologists on a property he was retained to examine in the Eastern Townships. Whether or not the property was likely to prove a promising investment hinged on certain geological considerations, the pros and cons of which were not easy of elucidation to the lay mind. With the aid of a very excellent sets of photographs, however, the conditions affecting the problem were very plainly set forth, and the engineer's clients were at once enabled to follow with perfect understanding the text of the report submitted to them. And so examples of the value of photography in report writing might be multiplied, if, indeed, any proof to that end were needed.

It is obvious, however, that photographs intended to illuminate technical writing of any description are of no service at all unless (1) they are as nearly as possible beyond reproach technically and, (2) are intimately and definitely applicable to the subject in hand. An engineer's report is not strengthened by mere embellishments.

To be quite sure of securing satisfactory results in photography, there is nothing like doing the work oneself, and on the presumption that this advice will commend itself, a few suggestions as to the practical methods of working when in the field may not be amiss.

Before proceeding further, we may well first consider the question of suitable equipment. In selecting a camera the too general tendency is to attach undue importance to the qualities of lightness and compactness. These, of course, are very necessary considerations, especially to men whose work takes them into the wilderness for weeks or months at a time, when every additional ounce of toilsome carrying counts; but after all the essential thing is the efficiency of one's instrument, and it will not pay to sacrifice efficiency for matters of lesser account. At the same time there are unquestionably cameras on the market that combine the qualities of a reasonable lightness and portability with those of strength, rigidity and completeness. These do not, however, in the writer's opinion, include the type of small hand cameras using roll-films, which, though useful enough on occasion, are not pre-eminently suitable for serious work.

The ideal camera for the field geologist should be of the hand or stand type, to take plates or cut films of dimensions preferably not less than five by seven inches. It should be provided with a rising front, with both vertical and horizontal swing backs, with bellows capable of a generous extension to admit of the use of long focus lenses, and last, but not least, be sufficiently strongly made to resist a certain amount of hard usage, and to ensure absolute rigidity when in commission. The lens should be, of course, an anastigmat of good make, since flatness of field, good marginal definition and crispness of image at full aperture are indispensable requisites. It may well be of the type manufactured by Zeiss, known as the Protar, or of the Dagor type, manufactured by Goerz. These lenses have, as is well known, the great advantage of being convertible, and may be used either as doublets of relatively short focus, with a working aperture of from F/6 to F/7.7, or as singlets or long focus lenses giving good definition at F/12. Thus, a Zeiss Convertible Protar is really a battery of three lenses; and a suitable lens for use on a 5 x 7 camera would have a focus of (say) seven inches, when in common use as a doublet; while the single combinations of the lens would have equivalent foci of, respectively, eleven and fourteen inches. This combination provides a most useful reserve power. In the matter of shutters simplicity of construction is the main point to consider; but as will be shown later, the majority of subjects photographed for the purpose of geological record require time exposures, the shutter is a relatively unimportant part of the equipment. Other essentials are one or more Ray-filters or colour screens to fit on to the lens hood—a five times and a ten times screen are the most useful; a stout tripod; an actinometer; a portable dark-room lamp; a couple of dishes or better still a developing tank, for development; and a small stock of chemicals in cartridge or tabloid form. The entire outfit need not exceed a weight of seven or eight pounds, exclusive, of course, of the dry plates—and whenever practicable, glass plates should be carried in preference to cut films, which latter, if more convenient in compass, rarely yield as good results.

It is not unlikely that exception will be taken to the inclusion of the tripod, the colour screens and the actinometer among the equipment as above enumerated. They are all nevertheless most essential to the production of satisfactory results. The fact that the uncorrected photographic plate is untruly sensitive to certain colours of the spectrum is too well established to need emphasis. The rendering of colours and their true tonal relations is a first requisite in photographs of rock exposures or geological strata. To ensure such results it is absolutely necessary to employ colour-corrected or orthochromatic plates or films in conjunction with colour screens, and even with the fastest plates and the most rapid lens, this inevitably means that the shutter must be set for time, and the camera mounted on a tripod. To obtain, moreover, a negative of proper tonal gradation, the exposure must be as approximately correct as possible, and without the aid of an actinometer this is not always easy to estimate. Referring again to the use of the tripod, no exposure should be attempted until the subject has been carefully examined in the focussing screen. Not only is this imperative in order to determine the best point of view, but that one may judge in what measure the lens should be stopped down. It is commonly advisable to focus with the lens at the full opening, and to gradually reduce the aperture until all the planes are brought to the desired sharpness. The ray screen may then be fastened to the lenshood, and as some screens affect the focus, a final adjustment should be made with the screen in position. Consideration must also be given to the conditions of lighting. The sun should never, of course, be allowed to strike on the lens, and when photographing rocks care should be taken to avoid strong contrasts in light and shade. A cloudy day, when the sun is not too heavily obscured, affords the most favourable conditions; but in our climate, between May and October, we cannot often count on a diffused light or cloudy days, and consequently the only alternative is to select a convenient time of day either early morning or towards evening, when the sun's glare and power are less insistent. The duration of the exposure should err, if at all, on the generous side, the aim being to secure a negative of full gradation with no loss of detail even in the darkest shadows. This, with a moderately good but diffused light, such as one would get in the afternoon on a cloudy day in mid-summer, an approximately correct exposure to record a rock surface in shadow would, using a moderately fast plate say H. and D. 180, a lens stopped down to F/32 and a five times screen, be not less than five seconds; while probably ten seconds would be still nearer the mark.

At least a percentage of the plates and preferably all exposed when in the field should be developed at the earliest opportunity. Nothing can well be more annoying or disappointing than the discovery, after the close of the season's work, that one's photographic records are valueless in consequence of errors of exposure or judgment in the taking. By developing (say) one in every six or more plates at the end of the day's photographing, one may readily discover and even rectify mistakes of this kind, while the possession of such data will be of assistance in the prevention of future miscalculation. In reference to development, it is only necessary to add a word of advice. Most of the formulæ recommended by the plate manufacturers are calculated to give somewhat contrasty effects, which for work of this character should be avoided. It is, therefore, advisable to dilute the developer by the addition of water equal to an increase of fifty per cent. in volume. This retards the action of the developer, and results in the production of a rather thin well-gradated negative of a good printable quality, showing the finest detail in the shadows. The practice of using a dilute developer is especially advised in cases where under-exposure is at all suspected. As to the plates, extreme rapidity is not important, and, in fact, is often a disadvantage. What is required is an orthochromatic or preferably pan-orthochromatic plate of moderate speed, either double-coated or backed as a prevention against halation. The writer has used the double-coated Seed plate with much satisfaction; but if the fear of breakage or the question of bulk and weight puts the use of plates out of court, a fair substitute is the Kodoid film, manufactured by the Eastman Company. This film, being mounted on a card, is of the same register as glass plates, and also has the advantage of being to some extent orthochromatic and possesses the property of overcoming halation.

In nearly every instance in which photographs are used to illustrate a geological fact or statement, their value might be considerably enhanced if the relative scale or dimensions of the subject illustrated were but adequately suggested. This is no difficult matter. In a photograph of a wide extent of country, the inclusion of a figure placed at a distance of fifty to a hundred yards from the camera will be of material assistance; while in the case of the presentment of nearby subjects—a coal seam, or mineral vein, or a geological contact—an idea of scale is readily given by laying some object in everyday use and of easily recognized dimensions, such as a geological hammer, or better still, a foot rule, in a position, which need not however be a too conspicuous one, across the rock face and including it in the field of view.

Although for all classes of work infinitely better results will be obtained with the large sized stand camera, mounted on a tripod, and the employment of colour corrected plates, so much additional impedimenta will not always appeal to the consulting engineer making hurried trips from one part of the country to another. One of the chief disadvantages of a small camera is the necessity of making subsequent enlargements of the negatives for reproduction or even reporting purposes,—and enlargements rarely equal originals in quality. There are also other drawbacks. Nevertheless, exceedingly compact and at the same time most efficient pocket instruments are now obtainable, and may be used with advantage under such circumstances as mentioned. Personally the writer prefers, even in small pocket instruments, the plate to the roll film type, since the former enables careful focussing to be undertaken when occasion requires, whereas the letter is restricted in this respect. An excellent little camera, very well adapted for the mining engineer's use; is manufactured by the well known London firm of Newman & Guardia. This camera, the "Sibyl," is made in two sizes, quarter plate and 2½ x 3½. The latter when closed is less than an inch in thickness and may be carried most comfortably in the pocket. Provided with a film pack it actually occupies less space and is considerably lighter than the ordinary roll film camera of similar plate dimensions, and consequently it is no hardship to carry, in addition to the film pack, half a dozen plate holders loaded with orthochromatic plates, a light tripod, and a colour screen, with which equipment any kind of work required may be attempted. The camera referred to is strongly made of aluminium. For ordinary purposes the movements are sufficient, and the construction and working parts are so simple that there is nothing to get out of order. It is usually provided with a Zeiss anastigmat lens, and the shutter is one of the most efficient on the market.

In the above notes the photography of rocks has been mainly touched on. There are numerous other subjects of which the engineer will desire a record, such as exterior and interior views of machinery plants, surface works, and underground workings. The photography of surface works and workings does not present any special problem or difficulty, and it is merely necessary to repeat the advice already given—to stop down the lens (say to F/16), mount the camera on a tripod, and use a colour screen and orthochromatic film, whenever possible. The photography of machinery, especially in a somewhat crowded interior, is not, however, easy. The main sources of trouble are halation and extreme contrasts. To overcome these, the use of backed plates is essential, while care should be taken not to include an open doorway or windows in the view. If this cannot be avoided, manilla paper should be pasted on the panes. When focussing, the lens at full aperture should be set at infinity, and then gradually stopped down until the nearest object desired to be included in the view is in sharp focus, which may best be determined by focussing on the flame of a candle. The exposure data must be calculated by the aid of the actinometer, but will, of course, be considerable, varying from a few minutes to half an hour or more. For machinery in motion, flashlight may be occasionally employed; but results are rarely satisfactory. It is an advantage to carry a supplementary wide angle lens for interior work, a lens of 4½ or 5 inch focus being suitable for use on a 5 x 7 plate.

For flashlight work underground, the plain magnesium powder is to be recommended rather than the compounds, since the powder is not only safe to handle, but the quantity necessary to illuminate any given area can be readily measured out. The following figures will, perhaps, be found of value in this regard. Using a plate of medium rapidity, and lens at F/16, the quantity of magnesium powder to illuminate a working with the wall ten feet distant, would be 1¼ teaspoonful. For fifteen feet distant, 2½ teaspoonsful; 20 feet distant, 4 teaspoonsful; and 25 feet, 5 teaspoonsful of powder.

DISCUSSION.

MR. MORTIMER-LAMB:—My object in presenting this paper is not only to invite attention to the obvious advantages of photography as an aid to engineering practice, but to advocate a more general attention to those details and principles on the careful observance of which successful and satisfactory results are essentially dependent. In my official capacity as Editor of the Transactions, photographs are sent to me from time to time for the illustration of papers contributed by members; and it is astonishing how comparatively few of these prints are technically beyond reproach—in fact in a great majority of instances they will not yield tolerable reproductions by the half-tone process. It seems to me the engineer should be just as particular when submitting a report to insure that the photographs illustrating and illuminating his points, are technically perfect and therefore true and convincing, as that the diction and language he employs to express his opinions and ideas is that of an educated man. One other matter: it is remarkable how greatly the attractiveness and, therefore, value of a publication is enhanced by good photographic reproductions and, as a case in point, it is not too much to say that the exceptional excellence of the illustrations published in the Annual Reports of the British Columbia Department of Mines has actually had a great deal to do in directing public attention to the mineral resources of that Province.

DR. A. E. BARLOW:—As Mr. Lamb has stated, I have a very keen appreciation of the value of photography as assistance in illustrating the reports of both mining engineers and geologists. In fact, in my opinion a certain knowledge of photography is essential to success in the practice of these professions. To the ordinary public a geological report, and even a mining engineer's report, is made much more intelligible and interesting if illustrated by good reproductions made from photographs that have been carefully and intelligently taken. Realizing these facts, it has been my endeavour not only to perfect myself, as far as possible, in the art of photography, but also to impress upon others its great importance. Last winter, when asked to take the Chairmanship of the Chibougamau Commission, I determined to provide for a good series of photographs illustrating the physical and geological features, forests, mining development work, etc., of the region to be examined. If it happened (as did happen) that our conclusions differed from those of certain mining engineers and geologists who had preceded us, the basis of those conclusions must be facts and not merely opinion or sentiment. Hence it was of prime importance that as many of these facts as possible should be illustrated by means of photographs, taken with as great care as the circumstances would permit. In connection with this work it was realized that every precaution must be taken so as to secure all plates and films from the effects of damp. Consequently, each dozen of plates and each two dozen of film packs were placed in tightly fitting tin boxes, specially made for the purpose. The roll films were also similarly protected. The cameras used were a 5 x 7 inch Premo Supreme fitted with a Zeiss convertible lens, and 5 x 7 inch Ideal camera (German make) with a Goerz Dagor lens. Besides these we had a 59 x 12 C.M. Ideal camera and $3\frac{1}{4}$ x $5\frac{1}{2}$ in. Kodak. These were all packed and carried to the region in a tin-lined box. At our headquarters we constructed a dark room, consisting of a log shanty measuring 6′ x 8′ x 6′. The interstices between the spruce logs were filled with moss; while the whole interior was covered with birch bark, A small frame door, also covered inside and out with birch bark, afforded access to the "holy of holies," as we called our dark room. This door was further protected on the inside by an opaque curtain sliding on wire rods. Suitable shelves were installed to hold the photographic materials and apparatus; while a ruby lantern was made from a dried fruit case, which was provided with a sliding glass covered over with two thicknesses of the red paper in which the Kodak film packs are wrapped. We were well provided with chemicals and developed both our plates and films in developing tanks. Sundays were thus very often employed in photographic work, as we had no opportunity of attending religious services. We did not notice any ill effects on our photographs by reason of this slight defection. Even with all these precautions we had a considerable number of failures, but, by developing on the spot, we were enabled to replace any defective negatives when desired. The negatives thus secured were carefully packed, and it may be recorded here that we suffered no loss from breakage, although we brought out with us over two hundred glass negatives, which were repacked in the same tin boxes which had contained the plates. For time exposures and most of the geological work, we used glass plates, finding that Seed's Double Coated Non-halation and Standard Orthonon gave the best results. The Edwards Isochromatic plates proved less satisfactory. Both the roll films and film packs were used for instantaneous or very rapid exposures, and, although the results secured were in general very good, the photographs were not so uniform as, nor equal in the matter of detail, to those taken on glass plates. It was a very trying atmosphere for photography. On clear days, however, the actinic power of the light was very great, and consequently advantage was taken of these conditions to secure distant and panoramic views. A great many days were characterized by a fine, steady rain (Scotch mist), and many of our photographs were taken during such weather. It was, nevertheless, found possible to take very good photographs of rock exposures or close views of mining development work on such days. For our rock work we used yellow screens of two degrees of colour, one requiring an exposure of three times and the other six times. In spite of the trying climatic conditions, we returned with several hundred very good photographs illustrative of this interesting trip.

MR. FERRIER:—I am very glad that Mr. Lamb has brought this subject to the attention of the Institute, because I have always felt that it has a most important bearing in connection with mining engineering work, and one that has been much neglected. One good photograph properly labelled is worth many pages of description, and in my own work I have always endeavoured to put as much as possible of the report in the form of good photographs, thus avoiding written detailed description. In my own practice I have made extensive use of photography underground. Ten or twelve years ago, at the time of a litigation suit in Rossland, my assistant, Mr. Arthur A. Cole, was instructed to take a comprehensive series of underground photographs bearing on the facts in dispute, and I think these photographs, which were clear and perfect, had, perhaps, a greater influence on the court than much of the other testimony adduced.

I am sorry to gather from Dr. Barlow's remarks that the morals of the Geological Survey remain on the same low plane. I know with us Sunday was the day for development. On one expedition in company with Dr. Barlow, I remember we had great difficulties changing plates under blankets; we had none of the facilities he describes, such as a log-house for development purposes.

With regard to underground work, it is really astonishing what you can do in the way of illustrating details in the examination of a mine. You can measure your angles from fixed stations and work out these details subsequently in the office on the map. I have always endeavoured to make photography and mapping go together. The photographs enable you, when mapping, to see and grasp many points which you would lose if you confined yourself merely to observations underground; and there can be no doubt that a good set of photographic records is of the utmost value in the preparation of structural maps.

In general, the applications of photography to mining are numerous and increasingly important, and I am glad, indeed, that the subject has been introduced for discussion.

MR. J. B. TYRRELL:—I may, perhaps, testify to what, in my opinion, is the legitimate use of the pocket or small camera for the engineer and geologist. There are, for example, many occasions on which professional men can employ a small camera to advantage, when the use of a more cumbersome instrument would be impossible or difficult. I have possessed for some years past two cameras, a 4 x 5 and a 5 x 7, and it is astonishing how frequently the larger camera remains at home, while the "4 x 5" accompanies me on my excursions. A man, however, has no excuse for not equipping himself with a yellow screen and light tripod, and thereby securing careful colour-corrected, properly focussed and intelligently directed results. In my own practice I employ two screens, one of which increases the exposure about three times and the other about seventeen times; and I have obtained, in cases where extreme correction for colour was necessary, some excellent results with the seventeen-time filter. The slight additional trouble occasioned by the use of the ray-screen is well repaid by the improved results. I would, meanwhile, recommend the geologist or engineer to remorselessly discard his photographic failures, retaining those negatives only that will yield satisfactory prints.

While I recognise that the glass plate or cut film is possibly superior in most respects to the roll-film, yet the roll-film system has, in my experience, one advantage over others, namely it is less easily affected by dust. Thus the roll-film when developed is invariably clean; whereas negatives on glass plates are often defective from pin-holes caused by dust setting on the sensitized surface prior to the exposure. As a matter of fact, many of my own negatives from roll-films exposed through a yellow screen, are most excellent; and I am convinced that good results are far more dependent on careful attention to the details of the process, such as correct exposure, careful selection of point of view, focussing, etc., than to the materials employed. On the other hand, the roll-film is so convenient and, if proper precautions be taken, will yield such satisfactory results, that I would not be disposed to recommend that its use be abandoned in favour of heavy glass plates, except under exceptional circumstances. In the old days, when the employment of glass plates was obligatory, it was considered a sufficient achievement if in the course of a season's work two dozen records were secured. Nowadays, with the lighter equipment, a man may without difficulty obtain a very much more complete set of photographs illustrative of his work in the field. As to the advantage of employing photography for the illustration of both public and private reports, there can of course, be no question. Speaking as a traveller, I consider that the series of about seventy or eighty photographs accompanying my brother's report on the Barren Land's, between Great Slave Lake and Hudson's Bay, published by the Department of the Interior, contributes essentially to its value and the report thereby conveys a better idea of that northern country than any other written on the region.

MR. JAMES McEVOY:—As a further contribution to this discussion, it has occurred to me that photography may be applied advantageously in the elucidation of detailed engineering problems, where one has to deal with levels and sections. In this regard I may, perhaps, mention that a gentleman here present, Mr. Howells Fréchette, was formerly associated with me in a work in connection with a large power installation, the plan for which necessitated complete contours. In the map prepared by Mr. Fréchette the position from which each photograph was taken is shown and also its application.

MR. FRÉCHETTE:—The work referred to was in connection with a hydro-electric power proposal at Elko, B.C. The scheme was to dam the Elk river at a point about 1,100 feet above the Elk falls, drive a tunnel 800 feet to the bed of the old river channel which was to be used as a forebay. A detailed survey was made, the plan of which showed contours at short intervals. On account of the cañon and cliffs, the contours merged into one another in places, making it difficult for those unfamiliar with plan reading to get a proper idea of the ground. Numerous photographs were taken showing these features and, on the plan, the points where the camera was set up were plotted as well as the angle of view of each picture. These photographs, together with the plan, conveyed a very clear idea of the topography.

MR. JAMES WHITE:—With reference to what Mr. Lamb said, respecting the Vancouver Power Company, that their engineer took photographs every day, I desire to say that, later, the Company was involved in a law-suit involving a large sum of money. These photographs were brought in as evidence, and the Company won without any trouble. If they had not had these photographs, they would have had considerable difficulty in proving their case.

DR. J. B. PORTER:—I think I may claim to be a veteran photographer, since my experience dates back to the days of the old wet plate process. I agree with Mr. Tyrrell that it is quite possible to make most excellent negatives by the employment of roll films; but I believe all experienced photographers will admit that the percentages of successes are far greater with glass plates. Personally I use both films and plates, and no doubt this is the common practice; but when I want to make sure of my result, I invariably make my negative on a glass plate. If portability must be considered, I prefer to carry a small camera equipped for plates rather than a larger instrument employing films.

That the mining student should possess a knowledge of photography has been recognized to some extent by the McGill faculty. Our students are generally intelligent men; but not one in three pretends to be able to distinguish between a good and a bad photograph. Not one in three understands the use of the actinometer, for example. To all, except the most experienced workers, the use of this instrument is essential, especially for the photography of interiors. Photography is not a difficult process to master; and consequently there is no excuse for an engineer who, knowing its value and application, neglects to perfect his practice.

MR. R. H. CHAPMAN:—In reference to the condition of note books mentioned by Dr. Barlow, and the difficulty of keeping legible notes in rainy weather, I wish to say that during the past summer the topographic mapping on Vancouver Island for the Geological Survey was continued into the rainy season; when a few hours' work in the brush was enough to practically destroy the note books. The work was done by plane-table and sheets of celluloid were used instead of paper. During the day's work the men would keep notes on the margin of the plane-table sheet and copy them into books at night. The Geological Survey has note books with celluloid leaves which are made for work under such conditions.

Pencil notes may be kept on celluloid perfectly; the memoranda may be wet and rubbed by clothing, brush or the hand without becoming illegible; but when dry they may be erased with an ordinary rubber eraser.

MR. D. B. DOWLING:—Photography has proved of great aid to the topographers of the Geological Survey, especially in the mountainous regions, where the difficulties of travel and the scarcity of roads or trails precludes the use of the ordinary surveying methods. Instead of traverses or plane table plotting, points are fixed by triangulation and from these and other points of vantage photographs are made of the intervening country. These views are all taken with a fixed focus camera and the plate is held in a vertical plane (checked by level bubbles on the camera) so that the horizontal and vertical angles can be measured from the plate or print. Horizontal positions for objects in the pictures are readily determined, and by maintaining the relative elevations of the station points, the contour of the intervening country can be plotted as well.

For consulting engineers who are called upon to make expeditions to mining areas under development it would seem that the principle underlying this method might be used with advantage, especially when the time for field work is limited and points of vantage from which to obtain views are to be had. The instruments required for this rapid survey are a transit of medium size, capable of reading vertical angles and equipped with stadia wires and a camera that can be adjusted by level bubbles so that the plate is vertical or nearly so. The photograph is then treated as a true perspective, and from bearings taken by the transit of objects in the picture, preferably points to right and left of the centre, the focal length is graphically determined, and from this other bearings to almost any extent may be plotted. With pictures from two stations it will be surprising how many points will be fixed on the plot by cross bearings. No extensive triangulation is necessary, as the photo-stations may be connected by stadia traverses. Another advance in photographic processes that promises to be of use to the geologist is the production of autochrome plates, whereby natural colours may be taken. Many photographs of rock faces, while giving details, fail to bring out such structural lines or lines of contact that are quite evident in nature but are hidden in the photograph. These failures are often due to the equality of the actinic value of two different colours. The autochrome plate promises much toward the solution of this difficulty. From four plates exposed last summer, as experiments, I cannot say that any are brilliant successes; but there were no failures, and it seems to me that their use will become general. The pictures cannot as yet be reproduced; but lantern slides may be made direct from the negatives.

MR. FERRIER:—With respect to the use of the actinometer to which Mr. Lamb makes reference in his paper, I may perhaps contribute a further remark. It is, that a mining engineer who is called upon to cover a wide territory in a very short time is very apt to overlook the fact that right conditions in one locality may be entirely different from those in another. One may go from the western coast, as I have done, where you get hazy, foggy conditions, down to the southwestern country and Mexico where the atmospheric conditions are most dissimilar, and forgetting this are thus apt to lose many important photographs by errors of exposure. The same thing applies in another way when you are in a locality under uniform bright light conditions, for instance in Mexico, where you often have such clear, bright light all day long that, late in the day, you are apt to overlook the fact that, whilst still bright, the light is not so strong.

With regard to the rival merits of plates and films, I find that in a dusty, alkali country it is almost impossible to protect plates from injury by dust, but you can protect films.

MR. TYRRELL:—The Duke of Abruzzi's experience in climbing Mount St. Elias is worth noting. He took with him two glass plate cameras and one Kodak employing roll-films. The only photographs he obtained that were found to be good enough for reproduction as illustrations for his book were those taken with the roll-film camera.

THE MINING LAW OF ONTARIO.

By SAMUEL PRICE, St. Thomas, Ont.

(Annual Meeting, Quebec, 1911.)

Laws regarding the disposition of public lands by the government and the exploration and acquisition and use of them by the individual for mining purposes, differ greatly in different countries and have varied much from time to time in Ontario; and probably no law upon the subject anywhere has ever had the very unanimous approval of those working under it, for individual opinions and points of view differ even more widely than the laws. Poor prospectors and rich capitalists, men with little and those with large experience; those who want to find something to develop and those who desire merely to get something to sell; the miner who wants to work the land for the valuable mineral he expects it to produce and the speculator who desires only to hold it while neighboring development increases its value—can hardly be expected to view matters in the same light or to desire the same kind of a law; nor is the interest of any of them always identical with the paramount interest of the community as a whole to which the property in the first place belongs; though, doubtless, in a country with the mineral promise and the large extent of minerally unexplored territory that Ontario possesses a liberal encouragement of individual enterprise, such as will promote discovery and bring about development, must in the end be the best policy.

As to what some features of a good mining law should be there can be little room for controversy. Simplicity in the requirements for the acquisition and holding of claims, and certainty and security in the miner's holding when these requirements have been complied with, may be set down as of first importance. It is also pretty generally agreed that some provision such as working conditions or periodical payments designed to cause development and prevent the blanketing and holding of lands in idleness or for merely speculative purposes, should form a part of every mining law. Simple machinery for determination of disputes and speedy finality in litigation are other very important matters from the miner's point of view. Uniformity of laws, which it has been suggested might be secured throughout Canada, would also, if it could be accomplished, seem a consummation to be wished, and perhaps not the least of its benefits would be the greater stability which would likely result from it.

Among the points upon which laws and opinions differ, two appear most prominent:—(1) Whether or not in the taking up of a claim, discovery of valuable mineral should be insisted upon, and (2) Whether absolute title in fee simple or only a lease or conditional title or right of occupancy should be given to the claim-holder.

The two points seem to a certain extent correlative—grant of absolute title going more or less logically with the requirement of discovery of valuable mineral, and lease or conditional title or right of occupancy with its non-requirement. Discovery is supposed to show, or to be some indication, that the lands are valuable for mining purposes and that they will in the natural course be so used, and is therefore some justification for an absolute grant under a statute authorizing the disposal of lands for those purposes. With such a justification lacking, the reasonable thing to do would seem to be to give only such a limited title or right of holding as will ensure or make it likely that the lands will not be held without being used for the purposes for which they were taken up. The different systems of mining laws have, at all events, in general followed these distinctions. For instance, in the United States, in British Columbia, and for some time past in Ontario, discovery has been required (though not very consistently enforced), and absolute title in fee simple has been given upon completion of a certain amount of development work and payment of what would, if the land were really valuable for mining, be a very insignificant price per acre; while in Nova Scotia, in Mexico and in Australia, discovery is not exacted, and only leases, titles dependent upon periodical payments, or rights of occupation upon working conditions, are given to the claim-holder. There is, of course, nothing to hinder combination of the requirement of discovery with the limited or conditional character of title (as seems in fact to have been the general rule in miners' customs), or the non-requirement of it with the granting of title in fee simple (as was at one time the case in Ontario), undesirable though the latter may be.

The requirement of discovery would seem to be the ideal principle for disposing of public lands for mining purposes, as under it the law is able appropriately to reward, and as far as possible retain the reward for, the prospector who has conferred a public benefit by bringing to light the hidden resources of the country, and this should encourage prospecting and lead to the opening up of valuable mineral. The great difficulty is to enforce the requirement and to make it operate fairly. It can hardly be denied that, with the exception of a few years during the height of the Cobalt excitement when government inspection was systematically carried out, the law of discovery in Ontario as well as in other places has been a good deal of a failure. The most, perhaps the only, effective method of enforcing it is by having a competent government official make an inspection of each claim. That this was of great benefit in the Cobalt district I think no one acquainted with the circumstances can seriously doubt. To carry it out in less rich and compact mineral regions is a matter of vastly greater difficulty, and perhaps the need is not so great. In response to what appears to have been the desire of the majority of the prospectors and miners of the Province inspection, except in disputed cases, has for the past few years been entirely withdrawn, and the effectiveness of the requirement of discovery has as a consequence been infinitely lessened. Some opinions would abolish the requirement entirely; others would allow claims to be taken up and held on working conditions without it but would insist upon discovery being made before issue of patent. A requirement so long existing and so widespread, having its origin in the earliest rules and customs of miners themselves, can hardly be without virtue; but the other requirement, as old and probably more general, that a claim-holder must continue to occupy and work his claim or lose his right to it, has perhaps on the whole been the more important and beneficial of the two. The substitution, as in Mexico, of payments of money for performance of work, is a variation which finds favor with some who would alter the present system.

HISTORY OF ONTARIO LAW.

Ontario did not, like so large a part of the United States, derive its mining laws from an influx of miners bringing in their rules and customs with them. In our early mining history, going back to about 1845, mining lands were disposed of under Order in Council, at first specific for each case, afterwards crystallized into general regulations. Under these many large areas were granted in fee simple at a small price per acre.

The first legislation, *The Gold Mining Act of* 1864, related only to gold mining and did not, as to other minerals, supersede the regulations.

After Confederation *The Gold and Silver Mining Act of* 1868 was passed by the Ontario Legislature. This followed in the main the provisions of The Gold Mining Act of 1864, but applied to silver as well as gold.

Both these Acts provided for the establishment of mining divisions, and for an officer to preside over them to record claims and determine disputes. The size of claims was very small and varied according to circumstances. A license was necessary, and the claim had to be staked out by planting a picket at each of the four corners. The title given was merely a right to occupy and work, and leaving the claim unworked for a space of 15 days or more forfeited it.

In 1869 was passed *The General Mining Act of* 1869. It superseded the previous Acts and applied to all kinds of minerals. The mining-division provisions were continued with some changes, but with them were enacted provisions for disposing of mining locations of 80, 160 or 320 acres. These might be purchased at $1 per acre, neither discovery nor working conditions being required, nor was it necessary to stake out the land before application.

This Act continued until 1890 with only one change—raising the price per acre in 1886 from $1 to $2. In 1890 an amendment was made allowing a location of 40 acres as well as one of 80, 160 or 320, and in 1890 also was passed *The Mining Operations Act*, enacting rules for safety in the working of mines.

In 1891 amendments were made requiring for the first time, so far as statutory enactment was concerned, the performance of development work upon mining locations (as distinguished from mining claims in mining divisions), the work being required to be done during the seven years immediately following the issue of the patent. It was also provided that instead of a patent in fee simple a lease for 10 years might be obtained for a mining location, the lessee to have at any time during the term the right to become the purchaser.

In 1892 all former Mining Acts and amendments were repealed and a new Act called *The Mines Act*, 1892, was passed, some new features being added, and The Mining Operations Act of 1890 being incorporated.

In 1894 and 1896 a number of amendments were made, which are not important for the present purpose.

In 1897 very important changes were again made. Discovery of "valuable ore or mineral" was for the first time (by statutory provision), required as the foundation for a mining location, an affidavit of discovery being required to be filed with every application. As to mining claims in mining divisions, the right to take them up was also expressly limited to licensees who "discovered a vein, lode or other deposit of ore or mineral"; a discovery post was required as well as corner posts, and the form and size of the claim were changed so that instead of being composed of 10 acres laid out along the course of the vein it was to be a square of 22½ acres laid out with boundaries running north and south and east and west, and in filing the claim an outline sketch or plan and particulars much as at present were required.

Again, in 1898, important amendments were made. It was for the first time provided that the holder of a mining claim in a mining division might obtain a patent or lease (at the price per acre charged for mining locations), after performing the prescribed development work for 2 or 3 years according as the claim was a square of 22½ acres or a square of 40 acres, the option of making it the latter being now given. The working conditions on mining claims were made five months of one man's time or its equivalent in every calendar year, the old provision requiring continuous working (barring intervals of less than 15 days and any time allowed as close season), being thus replaced.

In 1899 important amendments were again made, the main feature being a new plan for the taking up of mining land. It was provided that in unsurveyed territory not valuable for pine timber, a prospector after obtaining a license might, under regulations, stake out not more than two mining locations of 40 acres each in a year, and might hold them for two years, subject to an expenditure of $3 per acre of actual mining work the first year and $7 per acre the second year, after which he was to complete his application as in the case of ordinary mining locations. This Act also increased the number of years' work required to obtain patents for mining claims from three and two to four and three respectively, and changed the amount of work required on them each year from five months' work to $150 worth of work, computed at $2 per man per day, and provided that when the amount of work required for a patent had been done no further work would be necessary, thus putting them upon somewhat the same basis as to working requirements as mining locations, except that in the case of mining claims the work had to be done before patent and in the case of mining locations after patent.

Again, in 1900, more changes were made. Royalties, before provided for, were declared to be abandoned; provisions were made (to go into force by proclamation, but never enforced), for exaction of what were called license fees on nickel ores refined outside of Canada; and provisions were also enacted for requiring the raising of a specified amount of iron ore on locations and claims shown to be valuable for iron.

In 1905 further amendments were made, the most important being that leases only (and not patents), were to be granted in forest reserves.

Pausing to consider the state of the law just prior to the passing of The Mines Act, 1906, it will be observed that three distinct modes of acquiring mining lands were authorized, two of them differing from each other in almost everything required to be done:—(1) Applying for patent or lease on discovery without staking; (2) Locating under prospecting license on working conditions, and (3) Staking in mining divisions under miner's license.

The provisions relating to mining divisions, unimportant and pronounced to be a failure though they were for many years, came, in 1897, upon the establishment of the Michipicoten mining division and again in 1905, upon the establishment of the Temiskaming mining division (then including the Cobalt district), into very great importance. The power of supplementing the provisions of the Act by Order in Council was extensively used, and all provisions relating to mining divisions were published in the form of regulations, additions and amendments being made thereto by Order in Council from time to time.

Up to 1906 all questions and disputes as to claims or interests under the Act or regulations were dealt with in the ordinary course of departmental administration without resort to any special officer or to the courts.

THE MINES ACT, 1906.

In 1906 all prior Acts and all regulations made under them were repealed, and a new Act known as *The Mines Act*, 1906, was passed. It adopted the principle of one law for the Province and followed in the main, though with many alterations and additions, the provisions formerly applicable to mining divisions. It provided for the division of the whole Province into mining divisions and the establishment of local recording offices in all important mineral districts, licenses being required and being made good throughout the Province. The requirement of discovery was retained with a stricter definition and a better system of inspection for enforcing it. The working conditions were altered, especially as to the time for commencing their performance, and the size of claims was made more uniform. The granting of absolute title was continued much as before, the price being made $3 an acre in surveyed and $2.50 in unsurveyed territory; but the granting of leases (except in forest reserves), was dropped, and it was made compulsory to apply for a patent within 3½ years from the date of recording. For the more convenient and speedy determination of disputes and to avoid as far as possible suspicion of political influence in the disposition of claims, the office of Mining Commissioner was established and an appeal given to the High Court in all important cases. Working permits, giving exclusive rights for limited periods without discovery, were also provided for, but since the withdrawal of inspection these have been little used.

In 1907 extensive amendments were made, having chiefly for their object the better carrying out of the intention of the Act of 1906 and remedying defects which it was found to have. It was made clear, as had been intended in 1906, that a second licensee should not be entitled to stake over a prior claim while the latter subsisted; and, to prevent blanketing as a result of this rule, it was provided that unauthorized staking, and staking without recording, should disqualify the staker, and that disputes might be entered against invalid claims. It was also provided that prospectors while actively following up indications might protect their operations by prospecting pickets.

In 1908 a complete revision and consolidation of the Acts of 1906 and 1907 took place (in the course of the work of the Statute Revision Commission), the new Act being called *The Mining Act of Ontario*. The provisions were rearranged in simpler and more systematic form and many of them entirely re-cast. Minor alterations and additions as to procedure and otherwise were made, but there was no change in the general policy of the Act. The most important alteration was the abolition of what was known as the close season (15th November to 15th April), which had formerly been excluded in computing the time allowed for performing the first instalment of work.

In 1909, and again in 1910, slight amendments were made; those of 1909 relating chiefly to the operations of mines, and those of 1910 to reports of work and certificates of performance of working conditions.

The Premier of British Columbia is said to have claimed some time ago as the chief virtue of his administration of mining affairs that he let the law alone long enough for people to find out what it was. Ontario during the last 20 years can boast little of that virtue. From 1890 to 1900 the changes were frequent and extensive and many of them fundamental. Since then the one radical change has been that of 1906, but less important ones have been numerous. It is interesting, however, to note that notwithstanding the many changes, much of our earlier legislation has persisted even to the present time. This is perhaps only an illustration that many of the conditions and difficulties with which all mining laws have to deal remain always the same.

THE PRESENT LAW.

The present Ontario law may be briefly outlined as follows:—

(1). Any one over 18 years of age who takes out a miner's license may prospect for minerals upon Crown lands, or lands of which the mining rights are reserved to the Crown, and may take up, work and acquire title to a specified area by making a discovery of valuable mineral, staking out and recording a claim, performing and filing proof of the prescribed development work, obtaining a survey if in unsurveyed territory, and paying a small price per acre; patent being given in fee simple upon the completion of these requirements.

(2). The claim or any share or interest in it may at any time be sold or transferred to another licensee, and transfers, agreements and other instruments executed by the recorded holder may, and to ensure preservation of priority must, be recorded, the recording office being the repository of title prior to patent, much as the Registry or Land Titles office is after patent.

(3). The validity of every claim is open to dispute for a limited time after recording, but when this time has passed a certificate of record may be obtained, and on satisfactory proof of performance of work a certificate may also be obtained for that, and these certificates in the absence of fraud or mistake are conclusive evidence of the performance of the requirements of the Act.

(4). Questions and disputes arising under the Act, either between individuals or between an individual and the Crown, are adjudicated by the local recorder or by a special officer called the Mining Commissioner, subject to appeal in important cases to the High Court.

(5). Rules and regulations are prescribed for the operation of mines (whether on patented or unpatented lands), looking to the safety of employees and the protection of the rights of other miners and for the collection of statistics.

All these matters are covered by the Mining Act, and placer mining, quarry claims and operations for pretroleum, gas, coal and salt are also provided for. Legislation by Order in Council, as to which so much complaint was at one time made, is not resorted to. There are no rules or regulations, even for procedure, except those contained in the Act; though in the setting apart of mining divisions, and for the withdrawal of lands from sale, and the extension of time for performance of work in specified districts, Orders in Council are still used; and of course in Crown forest reserves the prospector and miner, in common with others, must observe the Forest Reserve Regulations. The comprehensive scope of the Act and its definiteness of detail make it lengthy but give greater certainty and security to the miner's rights. Allowing prospecting and mining in forest reserves and on lands under timber license and lands of which the surface rights are owned by settlers, which can only be done under provisions necessary to protect the valuable timber and other interests, may cause complication, but it widens the field of the miner's operations.

In the groups of provisions above outlined (omitting No. 5 with which it is not the purpose of the present article to deal), it will be observed that the first group covers matters which are essentially questions between the applicant and the Crown ; the second, matters between individuals, in which the Crown is interested only as it is interested in the general welfare of the mining industry or of the community; while the third and fourth affect individuals as between themselves as well as individuals in their relation to the Crown. Bearing in mind this dual aspect of the Act will be of assistance in following and applying its provisions.

Each group will be dealt with under appropriate headings.

(1). REQUIREMENTS FOR ACQUISITION OF MINING CLAIMS.

(a). *License.*—A miner's license is required for prospecting and for taking up mining claims or acquiring or holding any right or interest therein before patent. It may be obtained at the Bureau of Mines or, except for a company, from any Mining Recorder, and is good throughout the Province. It is not transferable, and it must be renewed on or before 31st March each year. The fee for an individual license is $5 a year; partnership and company licenses are higher and vary according to the number of partners and the capitalization of the company.

(b). *Minors.*—Minors over 18 years of age have the same rights and liabilities as to mining claims and transactions relating thereto as persons of full age.

(c). *Agency.*—The requirements for taking up and holding mining claims may be performed by an agent, but for making discovery and staking and recording the agent as well as his principal must have a license.

(d). *Lands Open.*—All Crown lands and all minerals reserved to the Crown (called mining rights), are open to be prospected and staked out as mining claims if not already taken up, unless expressly excepted, and the exceptions are very limited (secs. 36-47). In Crown forest reserves prospecting must not be done without a forest reserve permit as well as a miner's license, nor work or mining operations without leave of the Minister. Lands under timber license are freely open for prospecting and staking; but work or mining operations must not be carried on upon them without permission of the Minister. Where the mining rights only are in the Crown, the prospector or miner must compensate the owner of the surface rights for any injury done. Particulars as to what lands are open can be had at the recording office, where a map showing all recorded claims is required to be kept for public inspection. Lands already under staking are not open to be prospected or staked out unless the prior staking has lapsed or been abandoned, cancelled or forfeited; but insufficient staking or failure to record within the prescribed time works an abandonment and leaves the lands open, though invalidity of a claim by reason of insufficient discovery does not.

(e). *Discovery.*—Discovery of valuable mineral is required before a mining claim can be validly staked out. What is to be deemed valuable mineral is defined by the Act. It may be briefly stated as something making it probable that a mine likely to be workable at a profit can be developed from the vein or deposit which is found. A prospector, however, who has found indications may protect his operations on an area 150 by 50 feet by planting prospecting pickets as provided in the Act, and so long as he is diligently and continuously pursuing his search no one else is entitled to make a discovery thereon. There is also the more formal but now little used procedure of obtaining what is (not very appropriately), called a working permit for cases where discovery cannot readily be made on the surface or without extensive operations. For this, land of the area of a mining claim may be staked out with three rings of notches on the posts and after 60 days, if no mining claim is staked out thereon within that time, the exclusive right of prospecting and of staking out a mining claim upon it may be obtained for six months, renewable for a further six months, on condition of performing operations to the extent of not less than 5 days' work each week, or the equivalent in less time, commencing not later than two weeks after the granting of the permit.

(f). *Claims—size, form, number, etc.*—Claims in unsurveyed territory must as nearly as reasonably possible be squares of 40 acres with boundaries running north and south and east and west, and in surveyed townships must be the aliquot part of a lot or section specified in the Act; but in special mining divisions the area is reduced one half. Not more than three claims can be taken up by a licensee in the same mining division in a license year; but there is no limit to the number that may be acquired by purchase and transfer. The boundaries go down vertically on all sides and all minerals within them are included in the claim.

(g). *Staking.*—Staking must be done promptly after discovery else the discoverer risks the loss of his rights by another discoverer intervening and completing staking before him. The method of staking is very clearly set forth in the Act (sec. 54). Posts (of the size and character long used in British Columbia), must be placed at the discovery and at each corner of the claim and the boundary lines must be plainly blazed and cut out, or, if there are no trees, marked by pickets or mounds, and a line must be marked from the discovery post to the northeast corner, and the posts must be marked with the staker's name and other particulars as specified in the Act. Requiring the planting of posts at the corners and the marking of the boundaries is the plan in use in Ontario since the earliest enactments. Trifling defects will not, but failure to comply substantially with the requirements of the Act as nearly as the circumstances reasonably permit will, invalidate a staking. Unauthorized staking or staking without recording disqualifies the staker from again staking out the same land or any part of it unless relieved against (sec. 57).

(h). *Recording.*—An outline sketch or plan of the claim must be made showing its form and measurements and the situation of the discovery post, and an application and affidavit in the form provided in the Act giving particulars of the boundaries and location of the claim and proving discovery and the date of staking, and showing that the lands appeared at the time to be open for staking, must be made out and sworn, and filed with the Recorder within 15 days after the staking, or where the claim is more than

10 miles in a straight line from the recording office within 15 days and one additional day for each additional 10 miles or fraction thereof. The fee for recording is $10.

(i). *Working Conditions.*—Thirty days' work of eight hours each, consisting of stripping, opening up mines, sinking shafts or other actual mining operations, must be performed on the claim within three months after recording, 60 days' during each of the next two years' and 90 days during the third year, and a report duly verified by affidavit giving particulars as specified in the Act must be filed with the Recorder not later than 10 days after the expiration of each period; but the work may be done and the report filed at any earlier time if desired. The holder of two or three contiguous claims may by first filing notice do the work on one or on two for all. Failure to perform the work or failure to file proof within the time specified forfeits the claim and leaves the land open to other prospectors; but in cases of death, illness, pending proceedings or other unavoidable cause, or of hardship, and where the default is merely in making the report, limited powers of relief are provided for (secs. 80, 85, 86 and 88). There are special provisions respecting claims in forest reserves and on lands under timber license and for extending the time by Order in Council (sec. 79).

(j). *Survey.*—A survey of a claim by an Ontario land surveyor is required in all unsurveyed territory, and if the Minister deems it necessary he may direct it in other cases.

(k). *Patent.*—As soon as the other requirements have been complied with application may be made for a patent of the claim (or if it is in a Crown forest reserve for a lease), and the application must be made not later than 3½ years after recording, the price to be paid for the patent being $3 an acre in surveyed and $2.50 in unsurveyed territory. The patent is granted in fee simple for surface rights as well as minerals, except where the mining rights only are in the Crown, in which case only half the above price is charged and the miner must compensate the surface owner for any injury or damage; but pine timber is in all cases reserved, and in the northern parts of the Province there is also a reservation of 5% for roads. In Crown forest reserves renewable 10-year leases are granted instead of patents.

(2). DEALINGS BETWEEN INDIVIDUALS.

(a). *Transfer.*—The holder of an unpatented claim may at any time transfer it or any share or interest in it to another licensee and the latter may work it and complete the requirements and obtain patent.

(b). *Agreements for Interests.*—To establish ownership or interest in a claim recorded in the name of another licensee either writing or material corroboration must be had and is sufficient for agreements made before the staking out of the claim; writing (as under the Statute of Frauds), is necessary for agreements made after the staking out.

(c). *Recording Transfers and Agreements.*—All transfers and agreements affecting a claim may, if executed by the recorded holder or by his attorney appointed by recorded instrument, be recorded upon the claim in the recording office if the signature is verified by an affidavit of execution made by a subscribing witness. Recording is necessary to ensure preservation of priority.

(d). *Title.*—What may be designated as a record of title to unpatented mining claims is thus kept at the recording office, and a purchaser desiring information should seek it there and may rely upon what he finds much in the same way as he would upon a search at a Registry office. After patent the title goes to the Registry or Land Titles office as the case may be.

(3). DISPUTABILITY AND INDISPUTABILITY OF CLAIMS.

(a). *Disputes against Claims.*—Any licensee whether he sets up an adverse right or not may dispute the validity of a mining claim at any time before a certificate of record is granted, provided he specifies the grounds of invalidity and verifies them by affidavit in the form prescribed by the Act and pays a fee of $10; but by amendment of 1910 leave is necessary after the validity of the claim has once been adjudicated upon or after it has been on record 60 days and has already had a dispute entered against it. This amendment was designed to prevent the harassing of the holder by successive disputes which might prevent the issue of a certificate of record.

(b). *Certificate of Record.*—After a claim has been on record for 60 days the holder may, if there is no dispute standing against the claim, and nothing making it improper to issue it, obtain from the Recorder what is called a certificate of record, which is final and conclusive evidence of the performance of all the requirements of the Act, except working conditions, up to the date of the certificate, but may, on application of the Crown or of any one interested, be set aside by the Commissioner for fraud or mistake.

(c). *Certificate of Performance of Work.*—This may be obtained if the Recorder is satisfied that the work has been duly performed, and is as to conclusiveness and as to setting it aside on the same footing as a certificate of record.

(4). ADJUDICATION OF DISPUTES.

(a). *Forum.*—Generally, all questions and disputes arising before patent as to the validity or subsistence of an unpatented mining claim or as to its transfer or ownership or as to any other right or privilege or interest conferred by the Act, are decided by the Commissioner or Recorder, subject to appeal as hereinafter mentioned. In practice, matters of difficulty or involving much taking of evidence are usually dealt with by the Commissioner, a transfer being made by the Recorder when necessary.

(b). *Appeal from Recorder.*—An appeal lies to the Commissioner from every decision and every act or thing done or refused or neglected to be done by the Recorder; but unless appeal is lodged within the time provided by the Act the Recorder's decision is final and binding.

(c). *Hearings.*—The procedure is simple and speedy. Matters are brought to a hearing by obtaining and serving an appointment with notice of the nature and grounds of the claim or dispute, service of the appointment alone being sufficient when the party to be served has already received a copy of the dispute or appeal. Hearings must ordinarily be in the local district. Proceedings are not invalidated by defects where justice has been done.

(d). *Decisions.*—All decisions must be entered in writing, and the parties affected must be notified of them by registered letter mailed not later than the day after entry.

(e). *Appeal from Commissioner.*—With a few exceptions specified in the Act an appeal lies to an appellate division of the High Court from every decision of the Commissioner; but unless taken within the prescribed time the Commissioner's decision is final and conclusive.

CONCLUDING REMARKS.

The Act has been criticized, sometimes severely. Probably, as already remarked, there is no mining law that has not been, except where distance and fancy have lent perfection. The Act of 1906, which was put through under emergency conditions, undoubtedly had many defects. Though lengthy it was not clear or complete in its provisions, and it lacked systematic arrangement. In the amendments made in 1907, and the thorough overhauling by the Statute Revision Commission in 1908, these shortcomings were pretty well remedied; but the reputation of the present Act no doubt still suffers from the bad repute of its predecessor.

Most of the main features of the Act of 1906 and the present Act are in accordance with the resolutions of the Miners' Convention held in Toronto in December, 1905. Perhaps the greatest difficulty in satisfactorily working out the present law comes from the attempt to incorporate in it the various recommendations, often in their nature incompatible, made by the different miners' meetings, and in particular from retaining on the one hand the requirement of discovery, as desired by those who favor that principle, while relinquishing on the other, at the request of those who in practice if not in theory, oppose it, the two most effective means of enforcing it, namely, inspection and allowing restaking of claims without hindrance or delay where the existing staking is not based upon valid discovery. Some other things also, no doubt, could be made better; but in considering alterations the balance must always be struck between the benefit to be derived from them and the injury inevitably resulting from the unsettling and uncertainty consequent upon frequent change; and I think upon the whole the present Ontario Act has much to commend it. Its provisions are liberal and calculated to secure fairness and honesty of administration; prospectors and miners are given very wide privileges; mining lands can be quickly acquired and the expense, apart from development, is slight; rights are clearly defined and title is secure when the law has been complied with; disputes and litigation can be speedily disposed of; the provisions with which the prospector and miner ordinarily have to do are plainly stated; the Act, if long, is very complete, there are no supplementary regulations, and resort to other sources for the law or for information is reduced to a minimum.

Criticism, if well considered and specific, should be welcomed; but some that has been directed toward the Ontario Act in the past has been far from that character. Some of the comparisons also that have been made with foreign laws have evidently not been based upon complete or accurate information of what these laws are. The difficulty of framing an entirely satisfactory mining law, especially where valuable timber and agriculture are side by side with the mineral, is often, I think, not sufficiently appreciated. It must not be forgotten that the interests to be considered are various, and that men, even in mining communities, do not always act upon the golden rule.

MINING RIGHTS IN SEIGNIORIES IN THE PROVINCE OF QUEBEC.

By T. C. DENIS, Quebec.

(Annual Meeting, Quebec, 1911)

In the little hand book, called the Miner's Guide, issued by the Department of Colonization, Mines and Fisheries, of the Province of Quebec, for the use of the prospector, we find the statement that the rights to minerals, except gold and silver, belong to the owners of the surface rights in all lands situated in the townships, and patented previous to 1880. This measure corresponds to the enactment of the Ontario law which makes the same provisions for all lands granted previous to 1908. But in the paragraph next to this statement we find that in the Seigniories, as distinguished from the townships, the mining rights belong to the Crown, with only a very few exceptions. As the last title to a seigniory was issued in 1762, under the French régime, and the lands in the townships were granted or sold after the conquest of Canada in 1763, we cannot but admire the provisions of the old system, by which the underground rights remain to this day vested in the Crown, reserving to the Government the privilege of treating directly with those wishing to work the mineral deposits. Those who have had to negotiate for the acquisition of mining rights from private owners will readily appreciate the wisdom of this provision, and will realize that such reserve of the mining rights to the Crown is greatly to the advantage of the development of the mining industry, as compared with the regulations enacted subsequently, which were so loose and indefinite that it was thought advisable to wipe clean the slate and to relinquish all mining rights (except gold and silver) to the surface owners of lands granted between 1763 and 1880.

Hence at present we are confronted in the Province of Quebec with a state of affairs which at first sight might appear anomalous. Thus, on concessions of lands made previous to 1763, the Crown still possesses the mining rights and on lands patented between 1763 and 1880, the mining rights belong to the surface owners, except for gold and silver, which were always specifically reserved.

This provision of reserve of mining rights in seigniories is more important than might appear at a casual glance, for it affects an area of about 11½ million acres.

First of all, what are these seigniories on which the mining rights belong to the Crown?

Immediately after the discovery of Canada one of the first cares of the King of France was to colonize and settle the country as well as evangelize and civilize the natives "for the purpose of forming a powerful colony for the benefit of his subjects."

To promote and help such settlement, the governors of Canada had the authority to grant estates, For instance the letters appointing the Sieur de la Roche, Lieutenant General and Governor, in 1598, gave him authority "as respects said lands and those so to be acquired for us, to grant the same in full property to those who shall settle in said countries, in the form of Seigniories, Chatellenies, Earldoms, Baronies, etc." However, the results were far from satisfactory and the development of the country was slow.

In 1627, at the instigation of that great statesman, Cardinal de Richelieu, the King of France granted a charter to the "Company of the Hundred Associates," giving them "for ever" the whole territory of New France, with the right to grant estates to whomsoever they might deem deserving. We all know how the history of the Company of the Hundred Associates is closely connected with the Canadian history of the period. The property thus conceded, however, was not without onerous conditions to the Company, with which we are not directly concerned.

Among their privileges were the exclusive right to fur and other trading; the manufacture of arms and ammunition; the granting of estates with titles attached (titles to be subject to confirmation by the King) and the full possession of all mines and minerals. The granting of estates or seigniories was subject to certain conditions of settlement and dues, practically a variant of the feudal system then ruling in France, which made the Company of the Hundred Associates, in a measure, the agents of the Crown of France and made of the Seigniors, to whom large estates were granted, agents of colonization, for they were practically under obligation to grant, from these estates, lands to intended settlers, subject to certain dues to the Seigniors.

The conditions imposed upon the Company by their charter, among which was the establishment of 4,000 settlers in 15 years, were not fulfilled and in 1663 their charter was cancelled. We see by this action that although the powers granted to this company of the Hundred Associates were enormous, in reality its existence was entirely in the hands of the King, who was sole judge of the fulfilment of the conditions, was all powerful, and who, by virtue of the high handed exercise of his authority, might declare the forfeiture of the rights and privileges he had granted or even of those granted by the Company.

In 1664 another company, the West Indian Company, with similar powers and privileges, was formed, which lasted until 1674. But the settlement results were likewise unsatisfactory. From 1674 to the cession of Canada in 1763 the rights of granting estates such as Seigniories and fiefs were vested in the Governor or Intendant.

It is during these three periods, from 1627 to 1763, that practically all the estates were granted to seigniors—about 220 in all—embracing an area of 11½ million acres. Of these Seigniories, 15 comprise over 100,000 arpents (92,000 acres); 100 between 28,000 and 100,000 and the balance contain less than 28,000 arpents each. It is remarkable that although the two companies until 1674, and subsequently the representatives of the King of France, had the right to dispose of the mining rights, it is only in a very few cases that the mining rights were granted to the seigneurs, so that when the charters of the companies were cancelled, the mining rights had not been alienated and they reverted to the Crown, except in the few cases mentioned which comprise about one-tenth of the 11½ million acres granted in seigniories. The territory which they occupy comprise a strip on both shores of the St. Lawrence River, of a very irregular width, according to the depth of land granted, extending from one to forty miles from the river. These areas are shewn on most of the large scale maps of the province and can be recognized by the fact that they are not subdivided into the regular townships, ranges and lots.

Of the 220 seigniories the following are the only ones in which the mineral rights were expressly ceded to the owners of the surface rights. In the case of the first four the Crown has retained a right to a royalty:—

Beauport and Beaupré, in the county of Quebec; Lauzon, in the county of Levis; the Island of Orleans in the county of Montmorency; Verbois, le Parc, and Rivière du Loup, in the county of Temiscouata; Terrebonne, in the county of the same name and Petite Nation in the county of Ottawa. These seigniories, except those of Petite Nation and Terrebonne which border on the Rivière Jésus and the Ottawa respectively, front on the river St Lawrence.

The mining rights in the Common of Laprairie, were also abandoned to the Society of Jesus by act 51-52 Vict. chap. 13.

In the seigniory of Rigaud-Vaudreuil, county of Beauce, gold and other precious metals belong to the seigniors (special deed of concession of 1846).

The iron mines in the fief St Etienne, situate on the St Maurice were abandoned to the seigniors, the St. Maurice Forges Company.

From the time of the conquest of Canada in 1763 to 1880, grants of land were made under various regulations and orders in council which in many cases made no mention of the mining rights. From 1796 to 1815, many patents to land grants reserved mining rights to gold, silver, copper, tin, iron, lead and coal. From 1815 to 1863, only gold and silver were reserved.

The first attempt of the Province of Quebec to legislate mining rights in this latter period was the gold mining Act of 1864. After this, various measures, mostly in the shape of Orders in Council were adopted, fixing certain definite prices for land for the exploitation of gold and silver, for phosphate lands, etc.

In 1880, the first Quebec general mining law was passed on the 24th of July, expressly reserving mining rights in grants and sales of Crown lands, and from that date, the reserves are well defined. However, between 1880 and 1901, frequent trouble having arisen as to the interpretation of the deeds of the lands disposed of before the enactments of 1880, it was decided in that year (1901) to abandon to the owners of the surface of the lands granted between 1763 and 1880, all rights to the minerals, except gold and silver, which had always been expressly reserved.

This measure of abandonment however in no way affects the seigniories before mentioned, in which the mining rights had not been expressly ceded to the seigniors and the Crown in that respect retains the same rights as before the cession of Canada in 1763.

Since then the Quebec Mining Law is present history which does not offer any particular historical interest.

THE MINERAL RESOURCES OF A PART OF THE YALE DISTRICT, B.C.—A DESCRIPTIVE SUMMARY.*

By CHARLES CAMSELL, Ottawa.

Yale District has been sub-divided by the British Columbia Department of Mines into nine Mining Divisions, namely, those of Kamloops, Ashcroft, Yal, Nicola, Similkameen, Vernon, Osoyoos, Kettle River, and Grand Forks. These include some of the most important gold and copper mining camps in the Province of British Columbia. The present purpose, however, is to limit description to a portion of the Yale District the nature of whose resources is not so well known to the general public; but these resources may eventually prove to be as valuable and important as those of the developed camps to the eastward.

Geographically the region whose mineral resources are here discussed may be described as being bounded on the south by the International Boundary Line, on the west by the Fraser River, on the north by the Thompson River, and on the east by Okanagan valley. This region covers an area of approximately 80 miles in width and 100 miles in length, or about 8,000 square miles, embracing the whole of the Mining Divisions of Nicola and Similkameen, and parts of Yale, Ashcroft, Kamloops, Vernon and Osoyoos.

Physiographically this district lies almost wholly within the Interior Plateau region, except for a portion on the south-west edge which includes the northern prolongation of the Cascade mountain range. This range, which rises in northern California and extends northward through Oregon and Washington, divides into two branches as it reaches the International Boundary.

* Published by the permission of the Director of the Geological Survey of Canada.

The eastern branch, known as the Okanagan range, continues northward into Canada with gradually decreasing elevations until it dies away in the Interior Plateaus region west of Dog Lake. The western branch is more persistent, and after entering the district in the vicinity of the Skagit River, continues northward as far as the Nicola River where it also disappears in the Interior Plateau region. In the bay formed by these two branches of the Cascade mountains, the stretch of Interior Plateau begins, and extending northward in a gradually widening belt reaches far beyond the limits of the region under discussion.

The general elevation of the Interior Plateau belt in latitude 50° is roughly 4,000 feet above sea level, and although the drainage is either to one side or the other the general average slope is downward towards the north. The plateau features can only be realized when observed in perspective from any one of the higher elevations in the district. From such view point the many deep valleys in the plateau disappear from sight, and the higher tracts coalesce to form an apparently level skyline.

The forest growth in this district, below an elevation of 3,000 feet, is often rather scanty, and the country has a park-like appearance, being dotted with irregular groups of woods or single trees. Above 3,000 feet it is heavily wooded with fir, pine and spruce up to the timber line, which is about 7,000 feet above sea level. Wild grasses grow naturally over a great part of the district, and afford excellent feed for horses and cattle.

GENERAL GEOLOGY.

Lying on the northeast border of this district is an area underlaid by very old crystalline gneisses and schists. These were named by Dawson the Shuswap Series, and are supposed to be of pre-Cambrian age. They represent the old British Columbia axis on either side of which stratified rocks of different ages were laid down in succeeding geological times. On the western border of this axis, the earliest rocks deposited are of presumably Cambrian age, and constitute the Adams Lake and Nisconlith series, the former consisting almost entirely of volcanic materials and the latter more largely of true sediments.

A strong unconformity intervenes between the Cambrian rocks thus laid down and the next overlying series, known as the

Cache Creek Group. The latter rocks have been determined to be of Carboniferous age, and consist of great or less important thicknesses of limestones interbedded with thinner beds of argillite, quartzite and volcanic ejectamenta. The area covered by the exposed rocks of the Cache Creek Group is by no means as great now as when originally laid down, for they have been invaded and replaced by plutonic rocks of different types, or have been covered by many small patches of later sediments and volcanic flows.

A second unconformity, representing a much shorter period of time, separates the Carboniferous rocks from the Nicola Series above them. This series of rocks is of Triassic age and is also largely volcanic in origin, although it contains a few intercalated beds of limestones and argillites. Their area is probably larger than that of the Cache Creek rocks, though they also have been considerably reduced in volume by later batholithic intrusions or concealed by the deposition of more recent strata. The Nicola Series, and more often, perhaps, the Cache Creek Group, are the most important rock formations in the district from an economic or mining point of view. The Adams Lake and Nisconlith series are also sometimes important in this regard, as they contain some of the gold, silver, and copper deposits.

During Jurassic times and following the deposition of the Nicola Series, highly important events from a mining standpoint occurred in the geological history of British Columbia. It was during the Jurassic period that the intrusion of the great Coast Range batholith took place together with many smaller igneous bodies that are genetically connected with that batholith. These igneous bodies are made up of granitoid rocks varying in composition from a granite to a gabbro. It is generally on the borders of these intrusions that ore bodies are now found. Rocks of this age and origin are widely distributed over the whole of Yale District, and because of their intimate association with ore deposits, their contacts with older rocks should always be closely examined.

In the Cretaceous period, which immediately follows the Jurassic, local troughs or geosynclines were formed on the surface of this district, in which great thicknesses of sedimentary rocks were deposited. These troughs have a general north and south trend, and were situated, one at the head of the Roche River and another in the valley of Fraser River above Lytton. They are made up of sandstones, shales and conglomerates, with small beds of coal, although no workable seams have as yet been found.

A second period of eruptive activity is recorded in Tertiary times by the occurrence of smaller granitic bodies distributed throughout the district. These intrusions are difficult to separate from those of the former period, because of the lithological similarity of both series; but they likewise are of importance as being responsible for the formation of certain ore deposits in the associated stratified rocks.

In the Oligocene period small local basins were formed in certain places in this district. In these basins fresh water sediments were laid down, in almost every case with certain beds of coal. These basins are made up of sandstones, shales and conglomerates together with the coal. Remnants of these basins are now found at Princeton, Granite Creek, Nicola, Kamloops Lake, and several other points. The coal seams in them are generally lignitic in quality, except in certain cases where they have been compressed by dynamic action in which instances a bituminous coal has been the ultimate product. The area underlaid by these rocks is comparatively small; but it is believed that no single formation is of equal economic importance.

Both above and below the Oligocene sediments are great thicknesses of bedded volcanic rocks consisting of basalts, porphyrites, agglomerates and tuffs. These although covering a very large area, are relatively unimportant from a mining standpoint. Some gold, copper and cinnabar have been found associated with them, but these ores have not yet proved to be of any great value.

ECONOMIC GEOLOGY.

In compiling information on the ore deposits of this part of the Yale District the author has drawn freely from the published reports of the Minister of Mines for British Columbia, and from those of Dr. Dawson and Dr. Ells of the Geological Survey. In respect of the southern half of the district, however, the writer, who has been engaged during the past four years in an investigation of the geology of the district on behalf of the Geological Survey of Canada, has obtained his information at first hand.

The mineral resources of the district include a considerable variety of products, both metallic and non-metallic, namely, ores of gold, silver, platinum, copper, lead, iron, zinc, chromite, mercury and a few others of lesser importance. Of the non-metallic substances, coal is by far the most important; but there also occur in the district deposits of gypsum and asbestos, which though not at present developed may yet be found in such quantity and position as to make them of commercial value. Of precious stones, jade, semi-opal, garnet and amethyst are known, and it is not impossible that the precious or fire opal may yet be discovered.

The following description of these mineral resources merely summarizes the information so far available:

Placers.—In point of early establishment the placer mining of gold is second only to coal among the mining industries of the Province. To date, the value of the gold produced from this source in British Columbia, exceeds 70 millions of dollars. The industry, however, is gradually declining, and at the present time in the Yale District is almost extinct. In this region the most important streams on which placer mining has been carried on are the Fraser, Thompson, Nicola, upper Nicola, Similkameen, Tulameen, Coquihalla and certain small tributaries of these streams. Within recent years some dredging has been undertaken on the Fraser river below Yale, and though this work has been discontinued on account of an accident to the dredge, it is believed that other dredges will again be installed to carry on the work. Some placer mining is being done in Granite Creek in the Tulameen district, and developments are promised on the Tulameen River itself where platinum was formerly found in quantity.

Gold is the principal valuable metal of the placers; but in a few localities some native copper and silver have been found. The Tulameen district, however, contains placers which hold much platinum in association with the gold. These resources are not yet exhausted. The platinum output of the Tulameen district to date has been variously estimated at from 11,000 to 20,000 ounces. Within recent years there has been a gradual decrease in yield; but a revival of activity may be expected as a result of improved communication facilities following railway building. The productive area covers about 18 miles of the Tulameen river between Champion Creek and Granite Creek, and includes most of the tributaries of the Tulameen between these two points.

Lode Gold.—Between 85 and 90 per cent. of the gold annually produced in British Columbia from lode mines, is recovered from the smelting of copper ores. The remaining 10 to 15 per cent. is now from stamp milling and cyaniding operations, which are in the main confined to this part of Yale district.

Where gold occurs in association with copper in this district, the ores are as a rule, chiefly valuable for their copper contents and so may be later described under that heading. Ores mined for their gold contents, principally or solely, may be divided into two main classes. In the one class, the gold is found free in veins having a quartz gangue, and in the other, in association with arsenopyrite either in veins or in deposits of other classes.

Free milling gold ores have been found, and to some extent, worked at Granite Creek in the Tulameen district, at Fairview near Osoyoos Lake, at Roche river and at the Golden Zone camp, near the head of Twentymile Creek.

On the eastern side of Granite Creek and on the divide, between this and Nine Mile Creek, some very rich veins of gold bearing quartz cut the green schists of the Nicola series. The veins are, however, narrow and the gold is not evenly distributed. Veins of this character are partly at least the source of the rich placers of Granite Creek.

At Fairview two strong and well defined quartz veins cut steeply dipping schists. Gold values are distributed sparingly and unevenly through the quartz gangue, the value of the ore averaging about $5.36 per ton, a grade not sufficiently high to afford profitable extraction.

Another area, known as the Golden Zone, is situated about 10 miles north of Hedley. The ore is deposited in a fissure vein containing pyrite, arsenopyrite, blende, chalcopyrite and some free gold in a gangue of quartz. The vein cuts granite as well as limestone, into which the granite has been intruded.

Near the mouth of Roche River, a branch of the Similkameen, south of Princeton, a few small gold bearing quartz veins cut chlorite and hornblende schists. These veins are only a few inches wide, and carry pyrite, chalcopyrite and tetrahedrite as the ore minerals. Gold tellurides are also stated to be found in these veins. The region is at present accessible only by pack trail, but in spite of this a small shipment of ore was made a few years ago, and is stated to have given excellent returns in gold.

Of the second class of gold deposits, namely those in which the gold is associated with arsenopyrite, the gold ores of Hedley are the most important. In these deposits the gold occurs in highly altered calcareous rocks at and near the contact of intrusive rocks of gabbroid characteristics. These deposits are of contact metamorphic origin, the gold occurring either free or intimately associated with arsenopyrite in a gangue of calcite, quartz, garnet, epidote and diopside. The other ore minerals associated with the gold are pyrrhotite, chalcopyrite, pyrite and blende. The ores are not entirely free milling, and the concentrates from the stamp mill are shipped to a smelter.

The Hedley mines are at the present time the most important of their class in Canada. The mines are operated by a joint stock company, the production representing a value aggregating two and a half million dollars, covering a period of six years. Meanwhile the promising nature of the mineral occurrences in this area, warrants greater mining activity than that at present manifested.

Gold associated with arsenopyrite is also known to occur in the valley of the Fraser River near Hope.

Gold ores have been mined to a limited extent at Siwash Creek, a short distance above the town of Yale. The ore occurs in a porphyry dike, which cuts through schists and slates, mineralized with pyrite. Quartz veins are also found cutting the slates. Much placer gold was formerly found on the Fraser River at the mouth of Siwash Creek, and it is supposed that the gold here found originated from the quartz veins above mentioned.

Silver and Silver-lead.—Although there are a number of localities in this district in which rich silver ores and lower grade silver-lead ores have been found, they have not been exploited. The most important of these localities are Summit camp on the head waters of the Tulameen River; Silver Creek, near Hope; Skagit River and Stump Lake. The deposits, however, have not been developed on account of the present lack of transportation facilities. Native silver has also been found at several points in the district.

At Summit Camp the silver is associated with galena in replacement deposits occurring along lines of fracture which traverse limestone. Zinc blende and pyrite are found with the galena. Not much development work has been done on these ore deposits, which nevertheless appear from surface indications to be of some importance.

The occurrence of silver ores at Hope has long been known The veins here are stated to be from 4 to 7 feet wide, and to contain silver-bearing tetrahedrite and some silver chloride. Analyses of the ore showed the presence of lead, copper, antimony, iron arsenic and sulphur, besides the silver.

Stump Lake, between Kamloops and Nicola, is an old and now almost abandoned mining camp. The deposits here are in veins from one to six feet in width traversing volcanic rocks of the Nicola series. The vein matter, consisting of quartz, contains pyrite, chalcopyrite, galena, blende and tetrahedrite, and the values are chiefly in silver with less gold. The silver is probably associated with either galena or tetrahedrite, and from assay return a yield as high as 400 ounces to the ton has been shown.

Argentiferous galena also occurs on the Skagit River.

A discovery of silver bearing galena is reported to have been made recently on Whipsaw Creek about 25 miles from Princeton. Some importance is attached to the discovery; but no technical examination of it has yet been made.

Copper Ores.—Copper ores are the most abundant and widespread of all the metallic ores in the district. Their geological distribution too, covers virtually every known formation of rocks. In every case a variable proportion of gold and silver is associated with the copper. In a few cases, such as at Aspen Grove and Kamloops Lake, native copper occurs; but in the majority of cases the mineral is in the form of sulphides. To mention all the localities in which copper ores are found would necessitate a reference to virtually every prospect in the district. A brief description of the more important localities must, therefore, suffice.

Copper Mountain camp is situated about 10 miles south of Princeton. Copper ores are here found occurring on the contact of monzonite with limestones. The ores appear in the limestone as ill defined bodies near the contact of the monzonite, or else in fissures traversing both the limestone and the monzonite. The mineralized area is large though the average grade of the ore is low.

At Independence Camp on the head of Bear Creek, is another large low grade copper deposit. The ore here lies in a granite porphyry dike, which is intrusive between schists and granite. The entire dike is mineralized with copper sulphides; but the values are concentrated only along certain lines of fissuring which traverse the dike, forming deposits of the Butte type. The siliceous nature of the ore is the principal drawback to the development of these deposits.

The gold-copper ores at Law's Camp, also on Bear Creek, are replacement deposits in limestone. The limestones are interbedded with schists, and are intruded by granite and dikes of granite porphyry. The replacing minerals are pyrrhotite, chalcopyrite, galena and blende. The values are fairly high in copper, gold and silver; but from the nature of their origin the ore bodies are hard to follow.

At Hedley copper ores are found as contact metamorphic deposits in limestone near the line of junction, between diorite and gabbro. These ore bodies contain a considerable quantity of arsenopyrite, in addition to chalcopyrite and pyrrhotite, with correspondingly high gold contents, often of sufficient value to admit of the mining of the ores for the recovery of the gold alone.

Deposits of similar character to the Hedley copper deposits are found on Riordan mountain at the head of Keremeos Creek. Near the mouth of Keremeos Creek other deposits occurring in altered limestone are, judging from the published descriptions, of the same character, and carry a fairly high percentage of gold and silver.

A great number of claims have been staked and are being prospected in the neighbourhood of the mouth of Five Mile Creek on the Similkameen River. The deposits are both veins and contact deposits situated on the contact of either granite or diorite, the principal copper mineral being chalcopyrite. Other deposits of somewhat similar character are located on One Mile Creek north and east of Princeton.

Important deposits of copper are situated about 4 miles south-west of Kamloops, and from these mines a considerable tonnage of copper ore has been shipped in past years. The ore deposits are associated with plutonic rocks, and occur in shear zones in the latter. Chalcopyrite is the principal copper mineral, and is found both in the planes of shearing and in the country rock on either side.

At Aspen Grove, which lies about 25 miles south of Nicola Lake, native copper and copper sulphides are found impregnating volcanic rocks that have been intruded by porphyritic and granitic eruptives. A similar occurrence of ore is found on Copper Creek, which flows into Kamloops Lake from the north.

Copper ores of some importance are being developed in Highland valley, but the nature of the occurrence has not been described. A few other points at which copper ores have been found are Roche River, Tulameen River above Tulameen village, Mara Lake, Thompson River above Spence's Bridge, and at Mamit Lake.

Iron Ores.—The most notable occurrence of iron ore in this district is that known as the Glen Iron mine near Kamloops. The ore here is magnetite, occurring in east and west veins or in lenticular masses in eruptive rock, and associated with some calcite and feldspar. The walls of the veins are distinct, and the ore does not appear to be of the nature of segregations from the enclosing eruptive mass, for it often contains fragments of the country rock. Some ore was formerly shipped from here to the Pacific Coast, but nothing has been done in recent years.

In the Tulameen district on Lodestone and Olivine mountains much magnetite occurs in irregular veins and lenticular masses in pyroxenite. In this case the magnetite is undoubtedly a differentiation product of the pyroxenite, and was segregated out during the process of cooling. No attempt has been made to exploit these deposits, which may yet become available for commercial purposes.

Magnetite has also been found to a limited extent in a number of other localities throughout this district, but nowhere in such quantity as to constitute an ore of iron.

Chromite.—On Olivine mountain in the Tulameen district, chromite occurs in variable quantity in peridotite. It appears in short irregular veins from a half to one inch in width, or in bunches in the peridotite. It is also scattered in individual crystals throughout the mass of the same rock. It is not connected with any system of fracturing. The chromite is in this case undoubtedly a segregation from the peridotite magma in the process of cooling. It is interesting that peridotite, which is rich in chromite, in this district often yields a small percentage of platinum on analysis, and this belt of rocks is believed to have furnished the platinum found in the placers of the Tulameen River.

Mercury.—Deposits of cinnabar, or sulphide of mercury, have been worked to a limited extent in the vicinity of Kamloops Lake. The cinnabar occurs in a gangue of quartz and calcite in irregular veins traversing basic volcanic rocks of Tertiary age. It appears as bright red specks, and can be detected both in the veins and in the adjacent country rock. Some stibnite, antimony sulphide, is associated with the cinnabar. A considerable quantity of rich ore was once taken from these deposits; but nothing has been done in recent years.

Mercury is also mentioned as having been found in globules in the native state in some parts of the silver ore of Silver Peak near Hope.

Precious Stones.—Although placer mining operations have been extensively conducted in the district, the records of the discovery of precious stones in placers are few. Pebbles of jade have been found in parts of both the Fraser and Thompson rivers, and have been utilized by the Indians as ornaments or adzes.

Garnet and some zircon are of common occurrence in the placers of the Similkameen district, and the former is found in the rock in many places as an alteration of limestone; but its value as a gem stone is not great.

Specimens of amethyst, occurring in geodes in the solid rock, have been obtained from the head waters of the Similkameen River near the International Boundary line.

Agates are found in several places where recent volcanic rocks have been extruded. Semi-opal occurs in considerable quantity along with agate on Agate Mountain, a few miles southeast of Princeton, and in the same locality small fissures which cut basic volcanic rocks of Tertiary age contain opaline silica. It is possible that both here as well as in other localities mentioned by Dr. Dawson the precious opal may yet be found, as the association of rocks is very similar to localities elsewhere in which it has been found.

Other Minerals.—Gypsum has been recorded as occurring at two different localities in this district. An important deposit lies on the north side of the Salmon River about 25 miles north-west of Vernon. This deposit of gypsum is interbedded with crystalline limestone and schists, and is apparently of considerable width and extent. The quality is stated to be of remarkable purity. It is associated with some andydrite. The commercial value of these deposits should be quite sufficient to warrant their exploitation for the manufacture of wall plaster.

Another deposit of gypsum, the extent of which is not known, occurs at Spence's Bridge on the Thompson River.

Small veins of asbestos have been found in a belt of peridotite that crosses the Tulameen River about the mouth of Eagle Creek. The fibre of these veins is of good quality; but in the veins so far examined it is too short to be of much commercial value. Small belts of peridotite, altered to serpentine, are known in other parts of the district, and it is possible that some of these may yet yield asbestos of commercial value.

Zinc is found in the form of blende in many parts of the district, more particularly in association with galena.

Tungsten in the form of Hübnerite, manganese tungstate, has been discovered on the head waters of the Ashnola River near the International Boundary line. It is found in fissures veins that traverse granite.

Nickel and cobalt have both been obtained by analysis from the gold ores of Hedley, and also from shear zones in the pyroxenite of Lodestone Mountain.

Antimony is found as stibnite in several parts of the district, and often in association with silver ores.

Molybdenite in small particles has been observed in the gold ores of Hedley, and in granite porphyry at the head of Bear Creek. It occurs also in some quantity at Champion Creek, where it has been formed as a contact mineral on the intrusion of granite into limestone. It also appears here in small veins associated with the granite.

Bismuth has been noted in the form of a telluride in the gold ores of Hedley, where it has been formed as a contact metamorphic mineral on the contact of limestone and gabbro.

The majority of the minerals last described are known in such limited quantity that their occurrence is merely of academic interest, which fact, however, should not deter the prospector from searching for larger deposits of these minerals which might be of commercial importance.

Clays suitable for the manufacture of bricks have not yet been largely exploited in this district. The presence of suitable clays for this purpose, however, are known, though their working depends for success on their proximity to a railway or the neighbourhood of a good local market.

Stone suitable for building purposes is not so easily obtained as might be supposed. The bulk of the rocks have suffered so much fracturing through earth movements as to destroy their value for masonry. Some of the more recent igneous rocks, however, particularly granites and basalts, have not been much fractured, and these could be utilized if transportation conditions were favourable.

Coal and Lignite.—Coal is probably the most valuable of the known mineral resources of the district. Two ages of coal-bearing rocks are known, the one Cretaceous and the other Oligocene in age. Only one of these, however, namely the Oligocene, has so far proved to be productive.

Cretaceous rocks are found in the valley of the Fraser River, and also in a wide belt of rocks extending from the head of the Pasayton River to the head of the Tulameen. In the latter belt, float coal is reported to have been discovered on the Roche River and also on the upper waters of the Tulameen, but no seams have yet been found in place. It is quite possible that coal was never formed in these rocks; but it is significant that extensive coal beds have been worked in rocks of this age in eastern British Columbia, on Vancouver Island, and in the northern part of the province.

Oligocene rocks occur in several small isolated basins throughout this region. The rocks in these basins consist of sandstones, shales, conglomerates and coal. Such basins are situated at Princeton, Granite Creek, Nicola, Quilchena, Kamloops, Enderby, Nicoamen, Okanagan Lake and White Lake. Each of these Oligocene basins contains some coal, and most of them contain several workable seams. The coal is generally a lignite of high grade, making an excellent fuel for domestic purposes or for gas.

Some of the basins contain bituminous coals, such as the railways require for steam raising, and these generally yield a firm coherent coke that will be used by smelters when the occasion arises. The fixed carbon in all these coals varies from 40 to 60 per cent., and the water from 1.3 to about 7 per cent. In most of them the ash is fairly high.

The coal formation of the Princeton basin covers an area of about 50 square miles, and includes a considerable though yet unknown quantity of coal. The rocks are inclined at low angles and are not much disturbed. A drill hole near the mouth of the Tulameen River, sunk to depth of 280 feet, passed through a total of 34 feet 5 inches of coal. In this depth three workable seams of respectively 4 feet 6 inches, 6 feet 7 inches, and 18 feet 6 inches thick, were encountered. The depth of this basin is at least 1,000 feet, and it is probable that it may contain other seams besides those enumerated. The coal is classed as a high grade lignite, excellent for domestic purposes, but non-coking.

At Granite Creek the coal basin covers about eight square miles, and here the rocks have been tilted and lie at angles of about 35 degrees. At least four workable seams are known, varying in thickness from 4 feet to 6 feet 6 inches. The coal is bituminous, and of good steaming quality. It also yields a bright, firm coke, but is high in ash.

The Quilchena basin lying on the south side of Nicola Lake is about 7 miles in length from north to south, and a maximum width of over 2 miles. Several seams of coal, varying from 4 to 6 feet in thickness are reported by Dr. Ells as outcropping on either side of Quilchena Creek. The coal is said to be bituminous.

The Nicola coal basin lies in the valley of the Nicola River, and extends from the lower end of Nicola Lake for 14 or 15 miles to the mouth of the Guichon or Ten Mile Creek. The maximum width of this portion is about 3 miles. The same basin then extends northward up Guichon Creek for about 7 miles, and here has a width of nearly 3 miles. The rocks dip in many directions, and at various angles, and some faults occur. Five different seams are being worked, varying in thickness from 6 feet to 18 feet 6 inches. The coal is bituminous, and yields a firm coherent coke.

A small area of coal-bearing rocks is mapped by Dawson at Nicoamen on the Thompson River. Some fragments of lignite have been found in this locality, but very little prospecting of the area has been attempted.

Coal bearing rocks also outcrop a short distance to the south of Kamloops, though no coal has yet been mined from this district. The known seams are very thin, but they contain a true coal rather than a lignite, making a firm coherent coke.

A little coal has been mined from a small area near Enderby, but the extent of this basin is unknown. Some prospecting for coal was also done on the west shore of Okanagan Lake, and two small seams were discovered, which contained a true coal of fairly high grade.

A small basin is also situated at White Lake, a short distance west of Dog Lake in the Okanagan valley. The area of this basin is unknown, as is also the quality of the coal contained in it.

GENERAL SUMMARY.

From the foregoing enumeration of its various mineral resources it will readily be seen that this district has a great variety of ore deposits, and the localities in which they are found show that no large part of it is without resources of some kind. It is true that of these localities not all will eventually prove to be productive; but the wide distribution of the deposits augurs favourably for future profitable mining operation.

Heretofore the district has produced both placer and lode gold, platinum, copper, coal and some iron. Of these, as yet, gold has perhaps been the most important. The indications are, however, that the production of gold will increase, for while the output of placer gold is bound to decrease, this will be offset by an increase in the production of lode gold. Coal is second in importance, but the rapid advance in coal output indicates that this industry will ere long occupy the premier position. The copper deposits are undoubtedly of great potential importance. The ores of copper, however, must necessarily be smelted, and consequently the availability of coking coal in the immediate vicinity is a most favourable factor.

The great obstacle to the development of the district in the past has been the lack of cheap transportation. Activity in railway building is now being evinced by both the Canadian Pacific and the Great Northern Railway companies. The main line of the Canadian Pacific circles the district on the west and north, and a branch line is extended to Nicola Lake from the north-west, while it is now proposed to construct a line passing through the centre of the district entering again at the south-east. The Great Northern Railway is extending its system from the south-east, and before long will have connection through the Hope Mountains to the coast. Meanwhile the British Columbia Government has voted money for road-building in the district, and the trunk waggon road that will eventually be extended from the coast to Alberta will pass through the southern portion of the district. As a result of these provisions a very considerable stimulation of prospecting and mining operations may be anticipated.

THE SILVER FIELDS OF NIPISSING.*

By REGINALD E. HORE, Houghton, Mich.

The portion of Nipissing district here described is underlain for the most part by rocks believed to be of pre-Cambrian age. A small area northwest of Lake Temiskaming is underlain by limestone, which Logan correlated with the Niagara of New York State.

The pre-Cambrian rocks can be conveniently referred to four series which are of widespread occurrence. The oldest is a complex of much metamorphosed igneous and sedimentary rocks designated as Keewatin. Intrusive into these is a series of granites and gneisses termed Laurentian. Lying unconformably on both of these formations is the series of sedimentary rocks to which Logan gave the name Huronian. Intrusive into all of these are masses of diabase referred to the Keweenawan. The Laurentian and Keewatin together comprise the Archean, and the Huronian and Keweenawan make up the Algonkian.

These rocks are characteristic of a large area extending from Lake Huron north-eastward into Quebec. In this and some other belts the Huronian rocks predominate, while it appears from the descriptions of various explorers the greater part of Northern Ontario is characterized by rocks of the Laurentian series.

The geological sequence is tabulated below: The chief divisions in the succession were remarked by Sir Wm. Logan in the early reports of the Canadian Geological Survey. Subdivisions were

*Editor's Note.—The above paper was submitted in competition for the Commans-Frecheville-Marriott prize. It has been considerably abbreviated (with the consent of the author) for the purposes of publication.

made by Dr. Barlow[1] and Dr. Miller[2] as the result of more detailed mapping. In order that the succession shall be more readily grasped by those familiar with better known pre-Cambrian areas, a slight departure has been made here from the nomenclature of these writers. Chief rock types in the various formations are briefly described. The official reports include many descriptions of these rocks. The structure, composition and probable origin of the Huronian[3] sediments and the Keewenawan[4] igneous rocks have been described elsewhere by the writer,[5] and some remarks on the petrology of the Keewatin and Laurentian rocks will appear in another paper.[6] Recently Messrs. N. L. Bowen[7] and W. H. Collins[8] have published articles on the diabase and related rocks.

ROCKS OF THE NIPISSING SILVER FIELDS.

I.—CENOZOIC.

Recent: Clay, marl, peat.

Pleistocene: (1) Coarse, unstratified material—sand, gravel, boulders; (2) stratified clay with some sand.

Great unconformity:

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[1] Report on the Geology and Natural Resources of the Area included by the Nipissing and Temiskaming map sheets (393pp) Geol. Survey of Canada New Series vol X 1907 the Temagami District Summary report of the Geological Survey of Canada, pp. 120-133. 1903.

[2] Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming. 14th Report of Ontario, Bureau of Mines, 66pp; pt. II, 1905: and 16th Report pt. II, pp1-116, 1907.

[3] Huronian Rocks of Nipissing, Ontario, by R. E. Hore. Jour. Geol., Vol. XVIII, No. 5, July-August, 1910.

[4] Diabase of the Cobalt District, Ontario, by R. E. Hore. Jour. Geol., Vol. XVIII, No. 3, April-May, 1910.

[5] Differentiation products in quartz diabase masses of the Cobalt district R. E. Hore. Economic Geology. Vol. VI, No. 1, 1911. pp. 51-59.

[6] Geology of the Cobalt District, R. E. Hore. Wilkes-Barre meeting Am. Inst. Min. Eng. June 1911.

[7] Diabase and Granophyre of the Gowganda Lake District, Ontario, by N. L. Bowen. Journal of Geology, Vol. XVIII, No. 7, Oct.-Nov., 1910, pp. 658-674.

[8] Quartz Diabases of Nipissing District, by W. H. Collins. Economic Geology, Vol. V, No. 6, Sept. 1910, pp. 538-550.

I.—PALÆOZOIC.

Silurian: Grey limestone with some interbedded greenish shales, and at the base an arenaceous conglomerate, correlated with Niagara of New York State.

Great unconformity:

III.—ALGONKIAN.

(*a*) Keweenawan: Igneous intrusives only. Cheifly quartz diabase and quartz gabbro with acid differentiation products. Some olivine diabase and diabase porphyrite dykes. These rocks have been called by Miller & Knight the Nipissing diabase.

Igneous contact:

(*b*) Huronian: Sedimentary rocks only.

(i) An upper series. Probably equivalent to Middle Huronian of Lake Superior district. Chiefly feldspathic quartzite with some conglomerate. The series is called by Barlow the Lorrain series.

Slight unconformity:

(ii). A lower series. Probably equivalent to Lower Huronian of Lake Superior district. Chiefly greywacke, shale, conglomerate, and feldspathic quartzite. The conglomerate pebbles are mostly of holocrystalline rocks, the matrix greywacke and grey shale. The rocks are seldom schistose, except as the result of contact metamorphism. This series is called by Miller and Knight the Cobalt series.

Great unconformity:

IV.—ARCHÆAN.

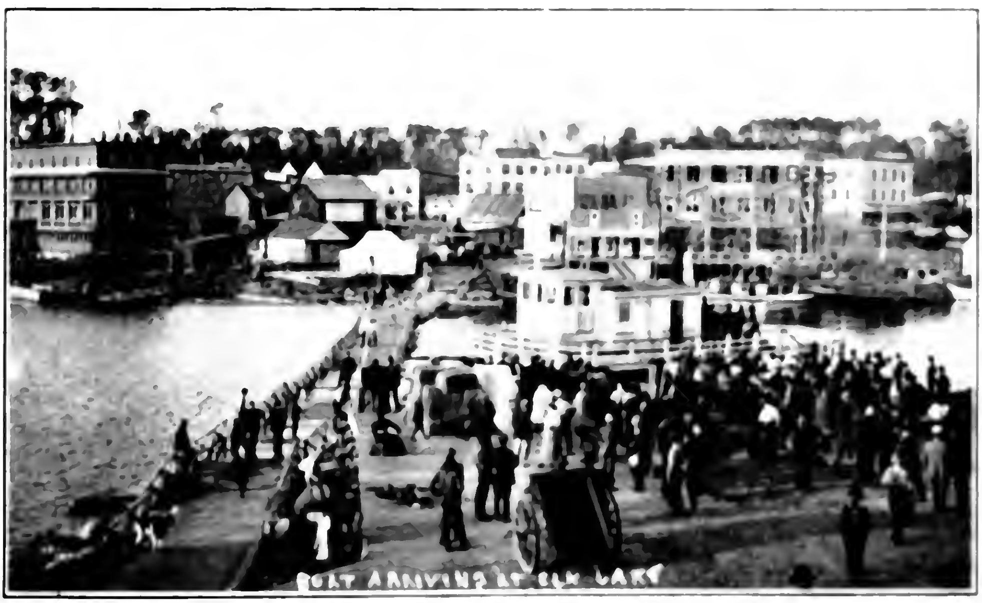
(*a*) Laurentian. Igneous intrusives only. Holocrystalline light colored siliceous rocks. Chiefly granites, diorites, syenites and gneisses.

Igneous contact:

(*b*) Keewatin. Igneous and sedimentary rocks. All much metamorphosed and many schistose. The relative age of the igneous and sedimentary rocks is doubtful. The igneous rocks are chiefly of extrusive types.

Elk Lake in June 1907. Bush fire in distance.

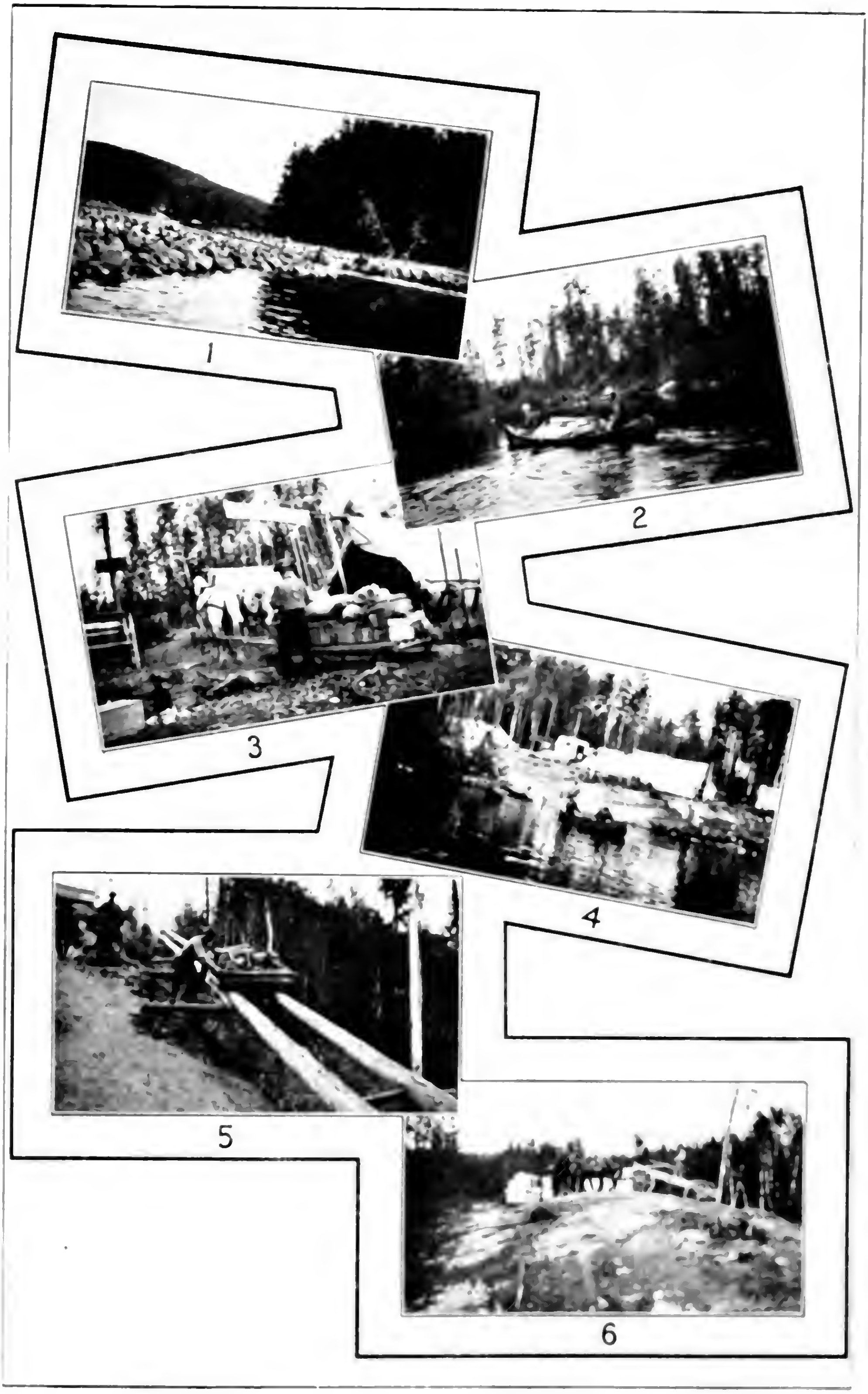
Photo by R. B. Stuart



Elk Lake in August 1909, photographed from the same spot as above

1. Pro[illegible] on contact of diabase and quartzite, Gowganda Lake.
2. Jointing in diabase, T. & N. O. Ry. cut, Giroux Lake.
3. [illegible] Mine. View looking west towards Maple Mt.

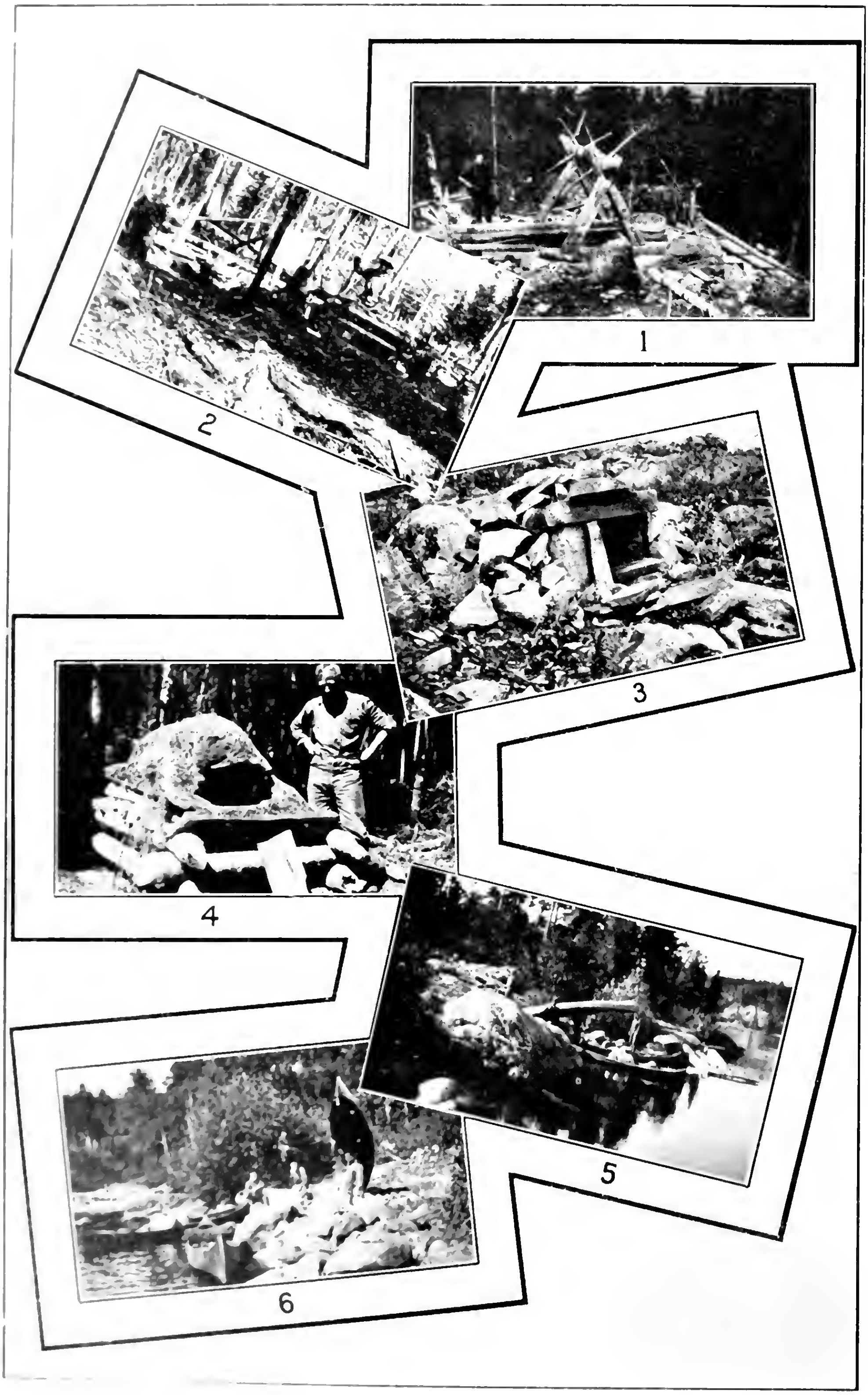
Photos by R. E. Hore.



Scenes on the Gowganda Canoe Route

1 Running a chute on the Montreal River
2 Taking in prospectors' supplies by canoe
3 Carrying freight on a "jumper" across a portage
4 A typical scene on a much travelled portage
5 Handling freight on a steep river bank
6 On Stoney creek portage

Photos by R. E. Hore



WITH THE PROSPECTOR IN NIPISSING.

1. A prospect shaft, Maple Mt.
2. A prospector's forge, Gowganda.
3. A stone oven, Oneima, Nipissing.
4. A clay oven, Montreal River.
5 and 6. Scenes on portages, Timagami.

Photos by R. E. Hore.

(i) Extrusives. (1) Dark coloured basic rocks—basalts —mostly with composition and texture of altered diabases.

(2) Light coloured siliceous rocks—felsite porphyries—mostly quartz porphyries which have been altered to sericite schists.

(ii) Intrusives. (1) Basic rocks, mostly diabase and gabbro, some lamprophyres.

(2) Siliceous rocks, mostly quartz porphyries and porphyrites.

(iii) Sediments. (1) The iron formation, chert, jaspilite, carbonates, slates and green schists.

(2) Fragmental volcanic rocks—a grey felsite agglomerate.

III.—STRUCTURE OF THE SILVER DEPOSITS.

In all the silver mines in Nipissing the ore bodies occur as fissure fillings. The veins are remarkably narrow, generally under six inches in width, and rarely over twenty inches. Naturally, therefore, the ore is in decidedly tabular masses. There is a tendency to call the masses lenses; but the resemblance is usually very slight. On either side of the main fissure silver in workable quantities is frequently found in minute veinlets as in a stockwork; but there is usually little or no ore disseminated as replacement deposit through the rock. The fissures, excepting the "mud veins," which are probably of more recent origin, are in most instances completely filled. Consequently well crystallized minerals are rare in the silver-bearing veins. The supply of vein material was evidently large as compared with the size and number of the fissures.

The outcrop of the veins is not easily detected. There has been no extensive weathering since the glaciers carried away the disintegrated portion of the country rock. Several veins of rich ore have so resisted the later weathering that it requires close examination to distinguish them, even after the overburden has been removed and rock and vein swept clean.

In other instances weathering has resulted in the alteration and removal of part of the filling and the position of the vein is indicated by a narrow fissure partially filled with dark earthy material. In the rich veins silver nuggets were found in this material. Some of the latter taken by Dr. Parks from the Little Silver vein in 1904, and assayed by the writer, showed as high as 36% silver, most of it in small particles of the discoloured native metal. These decomposition products were especially characteristic of veins not protected by a mantle or drift. As a rule the veins found outcropping at the surface were thus decomposed, while most of those found under a few feet of loose material are remarkably well preserved. There are, however, notable exceptions.

Dip of Fissures.—Many of the fissures are nearly vertical, and most of the others are steeply inclined. In the Huronian sediments the fissures are usually vertical and regular, passing indifferently through boulders and matrix in the conglomerate. Those in the Keweenawan diabase are usually vertical or steeply inclined and regular. Those in the Keewatin greenstones are usually inclined and irregular; but there are a few that are fairly constant in dip.

Persistence of Fissures.—The fissures are almost all very small. In most instances where they have been carefully followed for but a few hundred feet, they become so small and poorly defined as to be indistinguishable from the irregular rock jointing. Few of the productive veins have been followed over five hundred feet. The strongest fissure on the Nipissing property is No. 64, which has been drifted on for about 800 feet and is well defined at the 270 ft. level. The main vein on La Rose has been opened for a somewhat greater length, but not much developed below the 200 ft. level.

The depth of the ore-filled fissures has been found in many instances to be one or two hundred feet, and in a few instances four or five hundred feet. Up to date, comparatively little ore has been taken from below the 300 foot level, and most of it has come from a depth of less than 200 feet. A few deposits have been proven to greater depths. Beyond the depth at which ore is found some fissures continue and their limits are yet unknown; but others have become so poorly defined that they are confused with minor fractures. The distance which fissures have been followed after the loss of values has naturally varied according to the ideas of mine managers. At present there are few mines which have workings over 400 feet deep on producing veins. One of these veins (Kerr Lake) is in Keweenawan diabase; a second (Temiskaming) is in the Keewatin complex, in an area which is probably underlain at unknown depth by Keweenawan diabase, which reaches the surface further north. In the deepest workings in the camp there is good ore at a depth of 540 feet. The deepest extensive working on the Nipissing property is the 270 ft. level on No. 64.

While most of the fissures extend well defined to the surface, there are some cases in which fissures that are well defined underground show but a very narrow crack at the surface. Nearly all the highly productive veins show rich ore at or near the surface; but there are some good blind veins being worked and development will doubtless prove more of them.

Direction of Fissures.—The character of the veins has demanded careful stripping, and in consequence the direction of many of the veins can be determined very accurately at the surface with but little interpolation. The general strike of the more prominent veins at Cobalt, which were mapped by the writer for the Bureau of Mines, in 1906, is shown, with some additions, on Dr. Miller's map published in 1907. It is noteworthy that uniformity in strike is only found locally, and is only in a few cases very marked. More detailed mapping of veins underground shows them to be much more intricately connected than appears on the surface.

Distribution of Fissures.—At Cobalt there are valuable veins in the Lower Huronian sediments, in the Keewatin greenstones and in the Keweenawan diabase. Probably 90% of the production has come from the veins in the Huronian series.

In South Lorrain the veins are in the old greenstones and in the diabase.

Near Miller lake the veins are in the diabase and in Huronian sediments.

West of Gowganda lake and at Maple Mt., the veins are all in the diabase.

In Casey township the veins are in Huronian conglomerate.

Influence of Country Rock.—The most productive veins have been found in Huronian sediments, but there are also valuable deposits in Keewatin greenstones and in the Keweenawan diabase. None have been found in the upper series of the Huronian. Some of the fissures in the sediments terminate without reaching the underlying greenstones. Others terminate at or near the contact, while still others pass into the greenstones. Of the latter the majority show a marked decrease in silver content in the greenstones, though some show little change in mineral character. In the greenstones the fissures are usually irregular in direction and not infrequently pass into narrow stringers.

The marked change in character of some of the fissure fillings near Cobalt lake, in passing down from conglomerate into the greenstones, has been described by Dr. Miller, and similar changes have since been found in several mines.

At one mine a vein which has been enormously productive in the Huronian sediments has been found also to contain a high percentage of silver in the greenstones below; but is narrower and less regular there. At another mine a vein traced on the surface from the sediments to the greenstones shows high values in the latter, and on the same property a vein in the greenstones which was almost barren at the surface has been found to be very rich at depth. In some of the veins which have been described as losing their values in the greenstones, the values were lost before the contact was reached.

In nearly all cases there is a marked change in the character of the fissure in passing from the Huronian to Keewatin rocks. In most cases there is also a very remarkable change in the character of the fissure filling. In others there is little change. In nearly all cases where there has been a marked change in values in passing from the Huronian down into the Keewatin rocks the change has been a decrease.

In some cases fissures have been followed downward from Keewatin greenstones into the younger diabase intrusive. At one mine a marked change in the fissure filling was found. In the old greenstones the ore was high in smaltite and not especially rich in silver, while in the diabase some remarkably rich shoots of native silver were found.

Fissures have also been followed down from the diabase into Keewatin greenstones and into Huronian sediments. It is said that in passing into the Huronian shales under the diabase at one mine, better silver values were found.

In most cases where a fissure in one rock is well defined at the contact with a second it passes through; but is more or less deflected. The direction of the fissure has doubtless been influenced by the angle at which it meets the plane of contact; but there is little yet known concerning the position of such planes. One important vein is in Huronian sediments until it strikes a mass of diabase. It meets this at an acute angle, and instead of passing into the diabase it follows along the contact.

Outside of Coleman township so little development has been done that the change in passing to different rocks has not been determined. In many instances the fissures have been lost after being followed for a short distance in the diabase. In other cases the lack of values has caused the miners to cease operations before the depth of the fissure had been determined. In other cases values have proved better; but there has not yet been time for thorough development of the deposits.

Structural Features. In many of the workings it has been found that there are smaller parallel fractures a few feet from the main fractures. These are filled with similar minerals and in some cases have yielded much rich smelting ore. In many cases thin films of silver are found in a network of veinlets for several feet on the other side of well defined fissures, thus affording a very large tonnage of milling ore. One of the chief producers shows a system of more or less parallel ore filled fissures which are spaced a few feet apart and which occasionally converge.

In Cobalt there does not appear conclusive evidence that the opening of the fissures was accompanied by extensive faulting, though the structure displayed in certain workings at the north and south end of Cobalt Lake, indicates that there may have been a few large displacements. There are, however, some well known instances of minor faulting.

The Cobalt Hill vein of the Nipissing mines shows two horizontal displacements—this vein was one of the first discovered and has been described by Dr. Miller and Dr. Parks in their reports. On one of the most persistent fissures in the camp there are similar nearly horizontal displacements, or thrust faults, of a few feet, which are clearly shown in well stratified shaley greywacke and quartzite.

The diabase at Cobalt shows very numerous joints, many of which are perfect enough to control to an undesirable degree the breaking of the rocks. In these very thin cracks near the main fissure there is often a film of silver, and thus the wall rock may yield considerable low grade ore.

As a rule the ore in the wall rock is confined to the joints and crevices and is not disseminated through the rock. Specimens of wall rock which do not show silver minerals on the joint planes rarely give noteworthy assays even though the rock comes from the immediate contact with rich ore. That this is not true in all cases, however, has been demonstrated, and Dr. Adams has described one deposit in which the ore has apparently replaced the rock constituents.*

Origin of the Fissures.—It has been stated above that the strike of the veins in Cobalt shows a great diversity. In some parts of the district there is more uniformity in the fissure systems. Perhaps the most striking uniformity is that of veins running across elongated diabase ridges.

There is no reason to doubt that the contraction of the diabase on cooling developed fractures in it and in the rocks in immediate contact. The presence of aplitic veins may be taken as evidence of such fracturing, and a small amount of silver was deposited in these. It does not seem probable, however, that all the fissures were formed in this way. Those in Huronian rocks are nearly at right angles to the bedding planes. They may well have been developed in other ways. Possibly the great igneous activity was preceded and accompanied by great crustal movements, such movements being the immediate cause of the intrusions. Fissures formed during these movements would become the natural drainage channels for solutions escaping from the diabase magma.

The examination of the country rock indicates that in many cases there was no crushing of the grains nor severe folding of the strata. Here there has evidently been but inconsiderable grinding along the fissures, the rocks being merely fractured and but slightly displaced. In other cases the rock enclosing veins is much fractured and crushed for a width of a few feet. In the

* Note on the occurrence of the ore body at the City of Cobalt Mine. Jour. C. M. I., 1909, pp. 414-417.

mine workings such shear zones show numerous minor fissures along which the rock breaks readily, and the fracture surfaces are covered with a soft chloritic material. That the individual particles of the rock have been crushed and fractured is shown clearly by microscopic examination of some specimens. In thin sections of feldspathic quartzite, grains of plagioclase are seen to have been bent and broken and the parts displaced. The rocks along fissures of this character may have been under compression during deformation. That there was a strong lateral component is shown by the nature of the accompanying faults.

There can be but little doubt that the forces which developed channels for the movement of the diabase magma towards the surface were capable of and did produce small fissures into which the molten rock did not penetrate and fill. It is also clear from the shape of the diabase masses and from the nature of the joints in them, that fractures were developed in these masses and also in the rocks in immediate contact with the diabase by stresses produced in cooling.

It is convenient, then, to refer to two classes of fissures: those which were produced by the regional disturbances preceding and accompanying the diabase intrusion, and those produced by stresses developed in the igneous mass by concentration following on cooling and by collapse which followed the intrusion. To the second class belong evidently most of the fissures in the diabase, and some fissures extending to the adjacent rocks and radiating from the diabase masses.

It might be expected, then, that different types of filling would be found in the two classes; yet, while there are some differences of a minor nature, the most striking feature in comparing the contents of various fissures is their similarity. With native silver, calcite (dolomite) or smaltite or both are almost invariably found, and always in the same order of formation—first the smaltite, then calcite (dolomite) and silver last.

The difference in age would not be in all cases very great, many of those of the first class being formed immediately before the diabase intrusion, and some of the second class as soon as the molten material began to solidify and cool. Some of the latter were subsequently sealed by molten material, forming aplitic veins. Other fissures of the second class would be formed after the whole mass had solidified—a lapse of time by no means inconsiderable. If the ore-bearing solutions came from the diabase magma, as is supposed, rather than from leaching of the country rock, such similarity in composition of the fillings would be expected. It might well happen, however, that in the rich areas the latest filled fissures would contain an unusually large proportion of native silver—it being deposited after the smaltite—and there are numerous instances known where a thin film of the metal, with comparatively little smaltite, is the chief filling in joints in the diabase. In areas in which no great amount of silver has been found, similar joint planes are sometimes coated with a slight deposit of smaltite or cobalt bloom.

Summarily, then, fissures may have been formed immediately before the intrusion of the molten magma and also during its solidification and subsequent cooling. In silver producing areas all these fissures were filled with solutions containing similar substances, but in different proportions, and deposition in all cases took place after the diabase intrusion.

V.—THE ORES.

General Characters.—Native silver is the chief ore in most of the silver-bearing veins in Nipissing, while antimonides form the chief silver ore in a few veins. Sulphides occur in several veins, but form a small percentage of the ore shipped. Sulph-antimonides are also found.

According to Mr. Fraser Reid* at the Coniagas mine "argentite is confined usually to the contact of the conglomerate with the Keewatin, while pyrargyrite occurs in the form of a densy coating, or wash, in the wall rock of some of the workings."

Intimately associated with the silver there are always cobalt minerals, especially smaltite and cobalt bloom. While there are numerous cobaltiferous veins in which no native silver has been found, there are few, if any, native silver-bearing veins in which no cobalt minerals have been found. Niccolite is frequently found with the smaltite, and in a few veins is more prominent than the latter. A chloanthite-smaltite mineral is not uncommon; but is not readily distinguished from the pure smaltite. The

* Ore Dressing—Coniagas Concentrator. Canadian Mining Journal, Jan. 1, 1911.

chief gangue mineral in most cases is calcite, or dolomite. The carbonate is generally called calcite; but, as a complete analysis from two carloads of ore* quoted by F. N. Flynn shows, the carbonates are high in magnesium and have a composition near dolomite. In some localities quartz is more prominent, being especially characteristic of veins in the diabases. Silver has also been found with calcite in aplitic veins in the diabase; but not in economic quantities.

The values are very irregularly distributed. In many of the best veins there are very frequent and sudden changes in contents, so that of large samples taken a few feet apart in the ore shoots, some contain a few ounces of silver and others several thousand. With a few exceptions, shoots seldom show uniform value for more than fifty feet. The native silver occurs in various forms; but is seldom in well developed crystals. The greater part is found in irregularly shaped particles filling spaces between the grains in cobalt and nickel minerals, and in the carbonates thin plates and flakes are common. Capillary forms are rather rare; but in some veins occur in typical "wire" and "hair" silver. Some unusually well crystallized silver has been found at the Mann mine, Gowganda. Surface specimens have the usual black tarnish. Assays show a small percentage of arsenic and antimony and some of nickel and cobalt, the silver being, according to Dr. Ledoux, most universally alloyed with arsenic. Pieces varying in size from that of a marble to a hen's egg, have been found quite abundantly in some of the rich ore, and most of the silver is in particles large enough to be seen by the naked eye.

Composition and Value.—Silver is the only content of the ores for which the producers receive any important return. The other chief constituents are arsenic, cobalt and nickel. Nearly all the ore shipped contains a considerable percentage of these three elements; but only a few shippers report the assays.

The average silver content of the ores shipped is very high. Of 394 lots shipped to Ledoux & Co. during the first two years, 37.25% assayed over 1,000 oz. The smelting ores shipped in 1909 averaged 809 oz. per ton, and in 1910 about 800 oz. per ton.

The ores are in most cases classified in three grades: 1, high grade smelting ore; 2, low grade (siliceous) smelting ore; 3, milling

* Jour. Can. Min. Inst., 1908, pp. 293-334.

ore. The high grade averaged in 1910 about 3,000 oz. per ton; the low grade, 100 to 250 oz. per ton; the milling ore 27 to 40 oz. per ton. The smelting ore is shipped from the camp. The milling ore is concentrated at the mines.

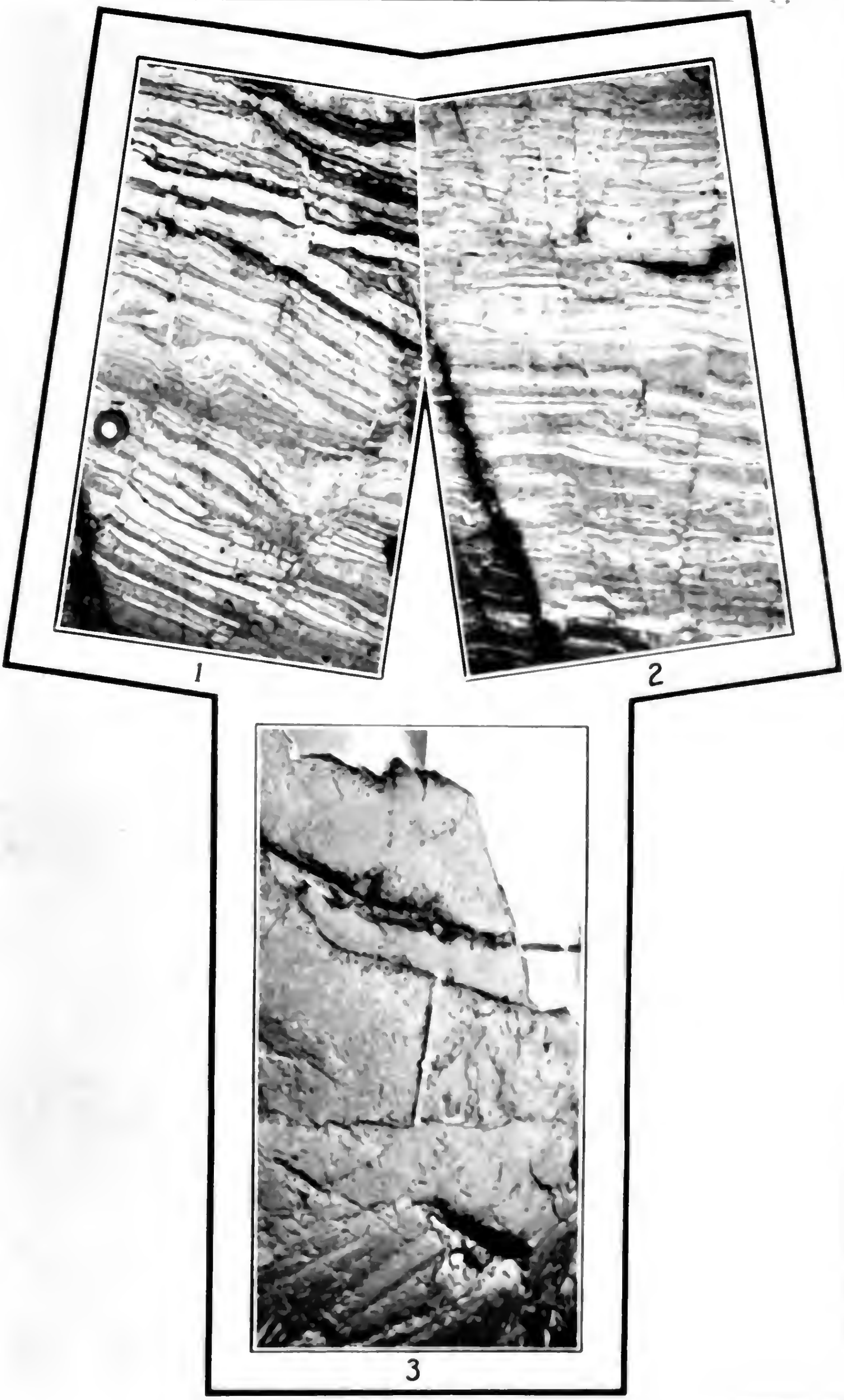
Most of the silver produced is in the smelting ores. In 1909 such ores yielded 22,437,295 oz., while the concentrating ores treated at Cobalt in the same year yielded 3,466,390 oz. silver. In 1910 the yield from smelting ores was about the same as in 1909; but the yield from milling ores was doubled. The shipment of bullion became an important factor in 1910, when about 800,000 oz. were shipped.

In 1910 the shipments were 27,394 tons of ore and 6,845 tons of concentrates. The average content of smelting ore and concentrates was 890 oz. per ton.

The Nipissing mines high grade ore shipped in 1909 contained 8·46% cobalt, 6·98% nickel and 40·93% arsenic; while the concetrates from milling ore contained 8·32% cobalt and 3·78% nickel. The La Rose high grade ore shipped in year ending May 31, 1910, contained 8·71% cobalt and 7·99% nickel; and the concentrates from milling ore, 7·10% cobalt and 6·36% nickel. High grade ore shipped from Hudson Bay mine in 1909-1910 averaged 8·88% cobalt and 9·89% nickel.

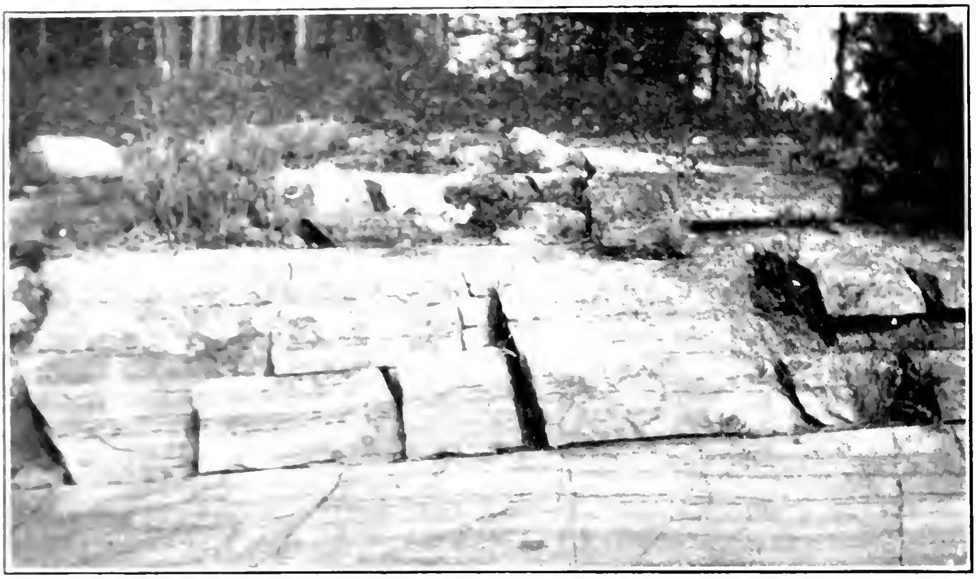
According to the official report of Mr. T. W. Gibson, Deputy Minister of Mines, the average silver content of smelting ores shipped in the years 1904–1910 was respcetively:—1,309; 1,143; 1,013; 677; 736; 809 and 800 ounces per ton. Concentrates 1908-1910 averaged 1,244; 1,174 and 1,100 ounces silver per ton.

For a few years the producers received some return for the cobalt and arsenic in the ores, but as the market for these substances is small, the price quickly fell, and recently there has been practically nothing bid. Up to the end of 1909 there were sold 3,951 tons cobalt valued at $511,173.00 and 12,895 tons arsenic valued at $160,070.00. During the past few years the price of white arsenic has fallen from 7 cents to 3 cents, and the price of cobalt oxide from $2.50 per lb. to almost a nominal price. During the year 1909 the Nipissing received $19,832.91 for 177,706 lbs. cobalt, and $14.04 for 117 lbs. nickel.



1 and 2. Folded and faulted jaspilite. Timagami, Ont.
3. Silver-smaltite vein 7½" wide, and glaciated country rock. Lawson Mine, Cobalt.

Photos by R. E. H.



Distinctly stratified Huronian shaly greywacke. Lake Timagami.

Photo by R. E. Hore.

Contact showing diabase lying on shaly greywacke. Savage Mine, Cobalt.

Photo by R. E. Hore.

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Open cut in Huronian conglomerate, Coniagas Mine, Cobalt. At extreme left are two narrow vertical silver-smaltite veins.

Photo by R. E. Hore

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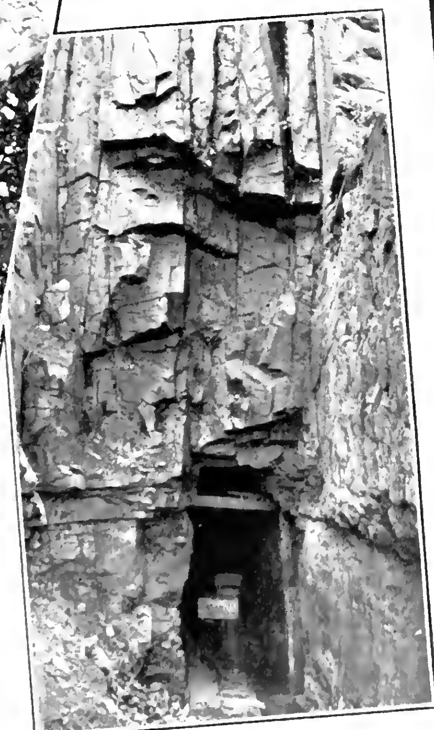

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1. [illegible] surface of Huronian conglomerate, Buffalo Mine, Cobalt.
2. [illegible] showing Keweenawan diabase (above tunnel) lying on Huronian greywacke.
3. Huronian conglomerate lying unconformably on Keewatin green schists [illegible] Timagami, Ont.

Photos by R. E. Hore.

Workings on Native silver vein in diabase. Timagami Reserve.

Photo by R. E. Hore.

Vent on silver-smaltite vein in Huronian sediments. La Rose Mine, Cobalt.

Photo by R. E. Hore.

For losses in smelting about 5% on gross value must be allowed, and for treatment 2% or more, according to grade of ore. For 1909, smelter deductions on Nipissing ore were 4·87%, and treatment charges 1·95%.

For La Rose mine ore, in 1909-1910 smelter deductions were 5·22%, and treatment charges 3·86% of gross value.

VI.—GENESIS OF THE DEPOSITS.

The character of the solutions which penetrated the fissures is to some extent shown by the material deposited. It is evident that silver, cobalt, nickel, arsenic, antimony, bismuth, sulphur, copper, iron and lead were present in these solutions, though the form in which they were present is not known. In the solutions there were also the constituent elements of water, calcite, dolomite and in some cases feldspar. The water may have been of meteoric or magmatic origin, or, more probably, both. It seems likely that the solution which deposited quartz and feldspar in aplitic veins was not hotenough to keep the water in a gaseous state. The more easily volatile constituents would naturally penetrate the rocks to regions of lower temperature and pressure. The water, metals, and carbon dioxide from the magma, and the meteoric water and its dissolved constituents together constituted the solutions which filled the fissures in which the rich ores are now found.

Conclusion as to Origin.—Nearly all the geologists who have visited Cobalt have remarked on the association of the silver deposits with masses of diabase. Dr. Miller, in his first report, gave it as his opinion that the ore probably originated from a diabase magma. Dr. W. A. Parks, who in 1904 examined a large area in addition to the producing section, insisted that the association was a genetic one. Dr. C. R. Van Hise, who visited the camp later, expressed the same view in a paper read at the Toronto meeting of this Institute, and suggested also that the Keewatin rocks had furnished the carbonates, while the chief function of the Huronian sediments was that of a recipient for the ores. Dr. Miller, in discussing Dr. Van Hise's paper, emphasized the abrupt change in values on passing down from conglomerate to Keewatin rocks, and pointed out the probability of repeated fissuring and filling. Dr. A. E. Barlow, in a discussion of deposits in the Montreal River mining division, emphasized the probably genetic connection of silver ores and diabase, referring especially to the feldspathic veins generally called aplite. Mr. N. L. Bowen made chemical analyses of some of the rocks, collected by the writer and concluded from his results that the aplites represent the end phase of the diabase intrusion.

He later examined other rocks rich in albite in Gowganda division, and concludes that a similar sodic facies has been developed by influence of the diabase on the argillaceous sediments. Mr. W. H. Collins made a special study of similar rocks in the Montreal Mining division and concluded that the extreme residual differentiation product of a diabase magma formed quartz-calcite veins carrying ores of copper, silver, cobalt and nickel. Mr. J. B. Tyrrell, in discussing Dr. Barlow's paper and one by the present writer, gives it as his opinion that the silver was in the diabase magma. Many others also have come to the conclusion that the diabase and the silver are genetically connected, and no one has expressed any decided contrary view.

If it be true that the diabase magma contained silver, it is evidently of importance that the rocks should be carefully examined to determine how those of the producing area differ from the hundreds of non-productive diabase masses in Nipissing. The determination of the mineralogical and chemical composition has not yet yielded any very valuable criteria. A consideration of the rocks intruded by the diabase seems to have given more valuable results. Of those who have written on the nature of the deposits, the chief discussion on this line is in the writings of Dr. Miller and Dr. Van Hise.

In a paper submitted to this Institute in 1908, the writer discussed the origin of the ores, giving reasons for believing that "the constituents were present in the diabase magma," that "the Keewatin greenstones have aided their deposition," and that "the chief function of the sediments was affording suitable fissures for deposition."

It was stated that "we may expect to find similar ore deposits where the diabase sills are associated with Keewatin igneous rocks, and especially valuable deposits where Huronian sediments are also present."

Three years have passed since these lines were written, and numerous discoveries have been made in various parts of Nipissing. It is interesting to note, therefore, that the hypothesis thus outlined is still tenable. All these more recently discovered deposits, like those at Cobalt, are in or near masses of diabase. The most productive, Miller lake and South Lorrain, are near the contact of diabase with Keewatin rocks.

There are some silver deposits in diabase, which are not near any known masses of Keewatin greenstones, and a few of these have yielded rich ore in small quantity. While such deposits have not as yet proved important producers, there is no *a priori* reason for this, and it may be expected that some such will turn out better than those now known. From what is known of the silver deposits in Nipissing, it seems that the most likely place to prospect is in localities where diabase intrudes Keewatin greenstones, and that in such localities the Huronian rocks should be carefully examined, as they afford the most favorable fissures for the deposition of continuous and regular ore bodies. Recent developments in Coleman township have shown that much ore will be mined from the Keewatin series, as well as from the Huronian.

DISCOVERIES[1] AT COBALT IN 1910.

During the past year the search for veins has been carried on in a most thorough and systematic manner. Miles of trenches have been dug in the glacial débris and the bedrock examined with extreme care. Some areas have been so thoroughly trenched in this way that the cross lines are but fifty feet apart and occasionally less. It is by this method that most of the recent surface discoveries at Cobalt have been made, and on the Nipissing property preparations are being made for the entire removal of the overburden. According to Mr. Watson, this company alone during 1910 dug 33.1 miles of trenches averaging 3·4 feet deep. These trenches, which are on ground which has already been prospected, are 100 feet or less apart. On the ground thus blocked out 24 new veins were found, including one very productive one, No. 122. Diamond drilling has been carried on at some mines,

[1]For history of early discoveries see The Mining World Nov. 25, 1911. "The discovery of silver deposits in Nipissing".

but will probably not play a very important part in prospecting until after the cheaper and more satisfactory surface methods have been pushed to the limit.

During 1910 numerous ore bodies were discovered at Cobalt on the properties of the shipping mines. A few good finds were made by surface trenching, and more will doubtless be made as the surface is more carefully examined. The underground developments were unusually favourable, and the year's work shows that more is expected at depth than the early workings indicated.

At the 160 ft. level on vein No. 73 of the Nipissing, a new ore body was found, showing 250 feet of high grade ore 6 inches wide, and a parallel vein 150 feet long and 2 inches wide. At the La Rose there was blocked out for 250 feet an ore shoot lying west of the main vein, and rich ore was found in the Keewatin at the 225 ft. level of No. 3 vein. At the Lawson, one vein, which gave but littel ore near the surface, shows in the Keewatin at the 188 ft. level, a large shoot of 5,000 oz. ore 8 to 10 inches wide. At the Temiskaming good ore was found in a winze sunk from the 500 ft. level, while an important ore shoot was found on the Beaver property adjoining. At the Crown Reserve, development proved some very rich ore at a distance from the larger ore bodies. At the Buffalo there was found unexpected length of ore in driving westward. At the Princess, rich ore bodies were opened at the 135 ft. level, and this mine became for the first time an important shipper. McKinley-Darragh and Savage Mines both improved greatly during the year, and Kerr Lake, Coniagas, Nova Scotia and Hudson Bay found new rich ore bodies.

Many other satisfactory developments resulted from development in 1910, and at the beginning of 1911 there was more ore in sight in Cobalt mines than at any previous time in the camp's history.

Change in Methods of Mining.—The early methods of mining at Cobalt have aroused considerable harsh criticism, especially from those who did not see the deposits until after their nature had been proven. The ore was in many cases taken out by open cut underhand stoping methods and the ground left in bad condition for deeper workings.

One property had produced several million ounces before any of the workings had reached a depth of 200 feet, and most of the mine owners extracted from open cuts a sufficient tonnage of valuable ore to render them financially independent before deeper explorations were undertaken.

For some time there were no expensive mining plants at Cobalt. To-day there are numerous remarkably well equipped mines, but since mining is not carried on to any great depth, little heavy machinery is in use. Nearly all the shafts are vertical and as a rule follow the ore for some distance. The levels are usually run at comparatively short intervals, many under eighty feet and some at less than fifty feet. Comparatively few of the shafts are over three hundred feet deep. The drilling is now done entirely by machine. The rock is in almost all cases quite hard and compact, giving firm walls in the workings, except where joints are unusually numerous. The problem of mining the ore is in most cases a simple one; but there are some mines in which the ore will not be all recovered so easily; notable cases being the upper part of the deposits under Cobalt and Kerr lakes.

In mining the narrow silver veins a large amount of country rock must be broken. It was soon found that in many cases the rock could be broken and removed without seriously disturbing the vein. The rich ore was then readily separated from the wall by hand picks and carefully collected—a method which gives an almost ideal separation at small expense. This clean ore was then brought to the surface, broken, washed and sorted into grades according to metallic content. In spite, however, of great care, much ore was lost, or rather, was mixed with the waste rock. Then again, ore shoots were found which could not be so readily separated from the wall. In a few cases it has been found advisable to keep the vein well within the breaking face, instead of leaving it on one wall.

In the early days much ore was sorted rather carelessly and even without washing. In consequence so much silver was discarded that a few minutes' search on the piles of rain-washed waste rock would usually result in the discovery of pieces of rich ore.

At most of the workings there is now brought to the surface with the rich ore a large amount of rock which carries low values

—twenty-five to fifty ounces. This is screened, washed and carefully hand sorted on tables or travelling belts. The rich ore and screenings are shipped directly to the smelters. The rock is treated in concentrating mills. The product of some workings on very small veins is sent directly to the concentrators without hand sorting.

DEVELOPMENT OF WATER POWERS.

During 1910 an important advance was the completion of hydraulic power plants,[1] which are now supplying the silver camp with compressed air and electric power. At Ragged Chute, on the Montreal river, the Cobalt Hydraulic Company have an air compressing plant designed for a capacity of 5,500 H.P. At Hound chute, Beach Bros. installed a 3,000 H.P. electrical plant for the Cobalt Power Company, and on the Matabitchouan river the Mines Power Company have a plant designed to generate 15,000 H.P. These power companies are supplying the mines with power at prices much lower than it could be produced from coal. The extent to which the mines are using hydraulic power is reflected in the report of the T. & N. O. Ry., which shows that while in 1907 the railroad carried 105,000 tons of coal to Cobalt, only 53,000 tons were carried in 1910. Hydraulic power was first available in April, 1910, and is now in almost universal use. There have been, as in most pioneer enterprises, some interruptions in service, arising from unexpected difficulties. Electric energy has been delivered with considerable success, but there has been some trouble connected with the delivery of compressed air. Waste of air before the installation of meters in the summer, and more recently an accident at the plant at Ragged chute, has interfered with the regularity of mining operations to some extent. The air from the Taylor compressor,[2] like that used at the Victoria copper mine, Michigan, contains but 17·7% of oxygen.

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[1] For description of these hydraulic power plants see A. A. Cole, Mining and Power Development in 1909, pp 28–47. Report of Mining Engineer of T. & N. O. Ry. Commission, Toronto, 1910; and E. T. Corkill, Report Inspector of Mines. Annual Report Bureau of Mines, Ontario, 1910, pp. 133–140.

[2] See "The Air from a Hydraulic Compressor, by F. W. McNair and G. A. Koenig. Minneapolis meeting of A. A. A. S., Dec., 1910, and Mining World, Jan. 28, 1911, pp. 249-250.

This deficiency, though slight, prevents the free burning of ordinary candles; but the acetylene lamps, introduced of necessity, have proved very efficient in this, as in ordinary air. As at Victoria mine, the lower oxygen content of the air has produced no apparent ill effects on the miners.

CONCENTRATING AT COBALT.

On account of the richness of the deposits, Cobalt was able for a few years to ship a large tonnage to the smelters without any investment in concentrators, and the greater part of the output is still from ores which go directly to the smelters. During the past three years, however, several mills have been erected. In 1910 there were in operation 14 plants, of a total capacity of about 1,400 tons per 24 hours, successfully treating ores averaging twenty to forty ounces per ton. All the mills use wet treatment, a dry process having been tried without success.

In the three plants first in operation, treatment was uniform in reducing with crushers and rolls. Experience showed that the wall rock was not easily ground to the desired fineness. Stamps were installed in the later plants with satisfactory results, the amount of slimes being not as excessive as was anticipated. Apparently the gain made in reducing the ore with stamps more than offsets the greater ease of concentrating the product of rolls. The treatment of the pulp from the stamps varies considerably in the different plants, flow sheets of which may be found in the official reports of Messrs. Cole and Corkill, and in the articles mentioned below.* Of the fourteen mills now in operation, eight, including Coniagas, Northern Customs, Trethewey, McKinley-Darragh-Savage, Temiskaming, Colonial, King Edward and Hudson Bay, are characterized by jigs, stamps and tables. Two of these, McKinley-Darragh-Savage and Trethewey regrind some sands in tube mills. In four mills, including Buffalo, Nipissing Reduction, Cobalt Central and Silver Cliff, rolls are used instead of stamps. In two mills using stamps—O'Brien and Nova Scotia—tables are used chiefly in separating a product

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* Hydrometallurgical Operations at Cobalt, by John Tyssowski, Eng. and Min. Jour., Dec. 24, 1910, pp. 1253–1258.

Hydrometallurgy of Cobalt Ores. By E. B. Wilson., Mines and Minerals, December, 1910, pp. 303–307.

for cyaniding or amalgamation. The Nova Scotia mill is the only one in which amalgamation is used. In the O'Brien mill the sands from a Dorr classifier are slimed in Hardinge tube mills, and then the tails from Deister tables are cyanided. At the Nova Scotia, concentrates from Deister tables are ground in an amalgamating pan, and the tails cyanided.

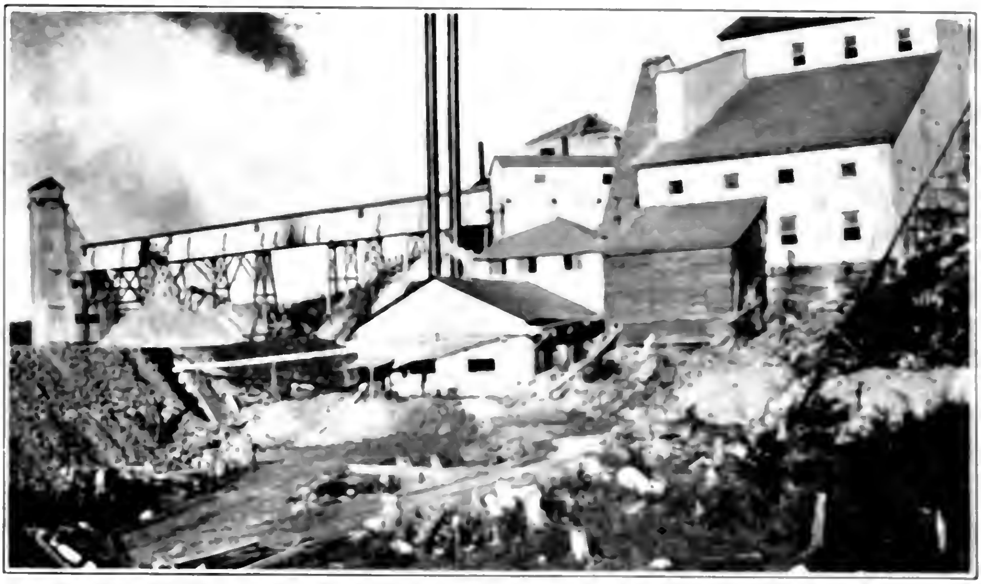
In 1909 the concentrators treated 129,072 tons. The ore averaged about thirty-five ounces silver, of which about 10 to 15 % went into the tailings. About one-half the recovery is in the jig product, which has a silver content about equal to that of the average smelting ore. At the Buffalo mill, in the year ending April 30, 1910, 33,708 tons of ore, containing 1,348,426 oz. of silver, were treated, and of this 78·60% was recovered as follows:—563,899 oz. on the jigs, 20,043 metallics picked from jig concentrates, and 475,958 oz. on the table. The ore treated averaged about 40 oz. per ton, and the 660 tons of concentrates averaged1,575 oz. per ton, and the bullion weighed 1,941 lbs.

La Rose ore, treated at Northern Customs concentrator during 1909–1910, averaged 28·58 oz. silver, of which 79·12% was recovered, while the tails contained 3·68 oz. silver per ton. The low grade ore from No. 63 vein, treated by Nipissing Reduction Company, averaged 27·94 oz. silver per ton. During 1910, the new mill at the Trethewey saved 86·4% from ore averaging 27 oz. per ton, and the Temiskaming is now recovering 88–90% on ore averaging 28·2 oz. per ton.

Since May, 1910, the mills have been operated by electric power, and thus important reduction made in costs.

Shipments of concentrates were: in 1908, 1,137 tons; in 1909, 2,948 tons, and in 1910, 6,845 tons. The average tenor was about 1,100 oz. per ton.

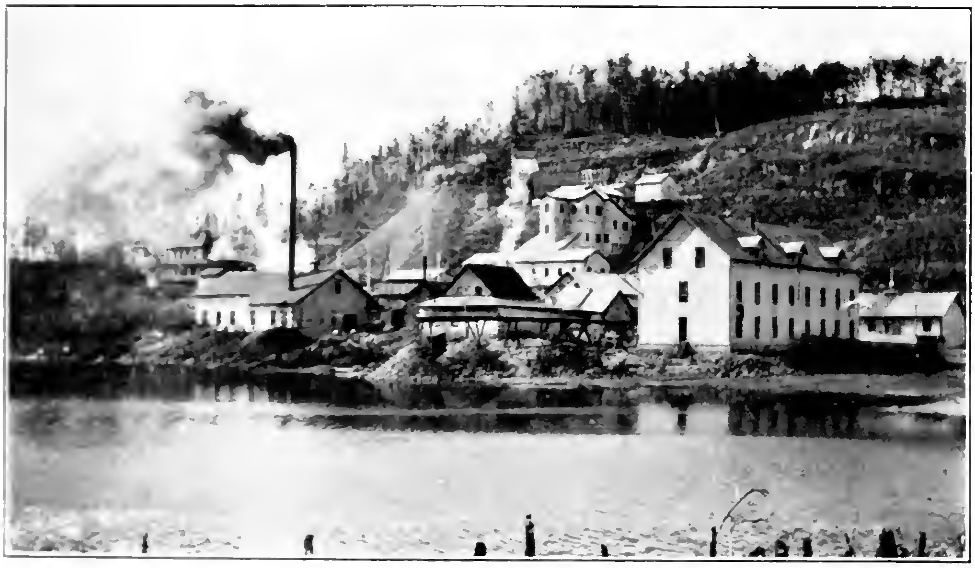
The milling ore, chiefly wall rock of rich veins, is hard and compact, and contains the silver in the native form. This silver is not commonly disseminated through the rock as a replacement deposit, but occurs rather as a filling, generally with smaltite or niccolite, in the minor fractures. Most of the ore is in the Huronian series, which are very fine to medium grained siliceous sediments. Ore in diabase is characterized by smaller percentage of the associated arsenides. The Keewatin rocks vary consider-



McKinley-Darragh shaft house and mill, Cobalt

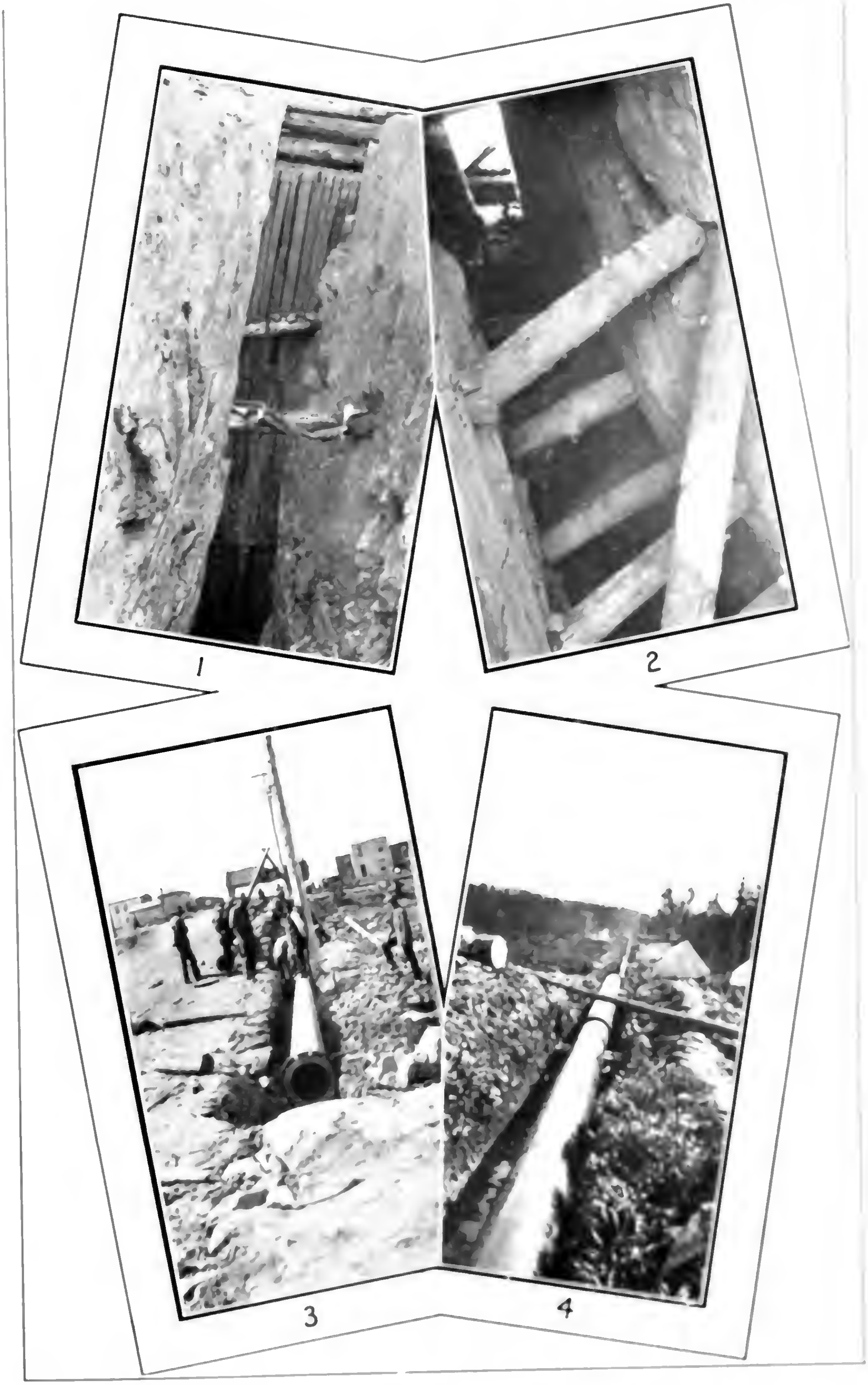
Buffalo mine and mill, Cobalt

Photo by E. F. Hess



Cobalt Central Mine and Mill.

Photo by R. E. Hore.



1 and 2.—Open stopes, Nipissing Mine, Cobalt.
3.—Laying compressed air line in Cobalt.
4.—Compressed air pipe line in Gillies Limit.

Photos by R. E. Hore.

able in hardness, some being harder than either the Huronian sediments or the diabase, either of which are crushed with difficulty.

CYANIDING AT COBALT.

During 1910 cyanide plants were in operation at three mines. In two of these, Buffalo and O'Brien, the process is to cyanide direct, while at the Nova Scotia the ore is first treated by amalgamation.

At the O'Brien plant, the stamp sands are re-ground in Hardinge mills, and the slime product cyanided, together with the stamp slimes. In consequence, about one-half the output of the plant is obtained by cyanidation, tables being used chiefly for classification. The settled slime is agitated for 30 hours with 4 lb. cyanide solution in Pachuca tanks, the resulting solution pressed through Moore filters, and the silver then precipitated by aluminium dust. The product is filter pressed and then melted. The bullion is refined in England.

At the Buffalo plant cyaniding as a recovery process is subordinate to concentration. In August, 1909, the practice of cyaniding silmes from the concentrator was begun, and by April 30, 1910, there had been treated 6,424 tons of slime, averaging 12·92 oz. silver per ton, of 83,034 oz., of which 66·08%, or 54,872 oz., were recovered by cyanide treatment.

At the Nova Scotia plant, concentrates from the tables are ground and amaglamated, and the tails slimed and cyanided. The pulp is treated 46 hours with 3½ lb. cyanide solution in Trent agitators.

In these three plants silver is being saved that would otherwise be lost, and the results are considered fairly satisfactory. It is reasonable to expect still better results, as experience with these uncommon ores is gained. Present profits, however, are not large enough to induce the general adoption of cyaniding at the other mines. At the Coniagas careful tests were made, and the conclusion reached was that present practice in cyaniding would not recover economically the silver in the tailings from the Coniagas mill, and the directors have decided not to install a cyanide plant. Sand tailings at the Coniagas contain 2·5 to 5·5 oz. silver per ton, according to nature of the wall rock treated, while the slime tailings contain 6 to 8 oz. silver.

During 1910 the amount of bullion shipped from the camp was about 800,000 oz., most of which was produced at the O'Brien plant. In 1911 the Nipissing Mining Co. has had in operation a new process for reducing high grade ore and has shipped large quantities of bullion. The company is also erecting a plant for the treatment of the low grade ore.

Reduction of the Ores.

Smelting was early recognized as the best method of treating the high grade ores; but it has not resulted in the erection of smelting plants at Cobalt. The early shipments went chiefly to New Jersey smelters. In 1906 the Canadian Copper Company began to receive shipments at Copper Cliff, and in the following year the Deloro Mining and Reduction Company were handling ore at Deloro. In 1908 the Coniagas Reduction Company began to handle at Thorold the product of the Coniagas mine. These three Ontario plants now recover about one half the silver produced from the ores of Nipissing district. Shipments to United States smelters, and some to Europe, continue, however. Much of this ore shipped in the crude state is low grade; the Ontario smelters treat only high grade. The shipments to Europe are comparatively small, and are of special grades of ore, including some very high grade from the Crown Reserve mine to Germany.

As was anticipated, the ores have been found difficult of treatment. The separation of the metals is made costly by the amount of time and labour involved in the process. Arsenic is recovered from the ore by roasting, and then the silver, with more or less arsenic, is obtained by smelting. The methods of recovering the nickel and cobalt differ at the smelters; but have not yet been made public.

Of the contents of Nipissing ores, silver is the only element which finds a ready market. Arsenic is very abundant, and, since it must be removed by roasting, it is saved in the form of white oxide. The arsenic has been a source of some revenue to the smelters; but the mine owners receive nothing for it, and the smelters are apparently now producing more than they can readily dispose of. Nickel has never been paid for, and ore with a high nickel content is not wanted by the smelters. Cobalt yielded a good return in the early days; but the demand for this metal has not increased in proportion to the supply. Until a few months ago, some of the buyers paid for cobalt in the ores; but the demand is so slight, that they have now accumulated large stocks of cobalt oxide for which there is no present market. The mine owners receive little or nothing for cobalt, and the smelters, while saving the oxide, do not place any great value on it.

COST OF PRODUCTION.

The profit from mining operations at Cobalt has been very remarkable, amounting to about fifty per cent. of the selling price of the ore. About $25,000,000.00 profits have been divided among the mine owners. Owing to the nature of the deposits, the cost of producing a ton of ore has been unusually high; but the narrow veins are so rich that the profit has been in many cases thirty, and in some forty cents per ounce of silver mined.

One Company, Crown Reserve, produced in 1909, 4,034,325 oz. silver at a cost of 10·31 cents per oz., and in 1910, 3,248,196 oz. at a cost of 11·97 cents. Another mine, Kerr lake, in the year ending August 31, 1910, produced 3,046,295 ounces at a cost of 13·27 cents per ounce (7·54 cents for mining and 5·73 for smelter deductions, treatment, freight, etc.). The other mines show costs slightly higher. Nipissing mine, the largest producer in the camp, reports costs for 1909 to be 16·39 cents per oz., and for 1910 14·72 cents per oz. La Rose mine, doing unusually extensive development work, reports costs for 1909-1910 to be 23·27 cents per oz. The profit on production for Nipissing in 1909 was 68·53%, and in 1910, 72·62%; for La Rose, in 1909-1910 profit was 56·10%; for Crown Reserve in 1909 profit was 41.25 cents per oz., and in 1910 was 42·13 cents per oz.

In 1909 ore containing 25,897,825 ounces of silver and valued at $12,461,576, yielded a profit of about $7,000,000, thus indicating the average cost to be about 21 cents per ounce. Four large shippers produced one-half the camp's output in 1909 at an average cost of 14 cents per ounce. In 1910 there was produced 30,558,825 ounces valued at $15,436,994, yielding a profit of about $9,000,000, thus indicating the average cost to be about the same as in 1909.

Silver Production (1904–1910).

At the end of 1910 the silver mines in Nipssing had produced ore containing 93,977,833 oz. of silver, for which the mine owners received $48,327,280. The net profit was about $26,000,000.

During 1910 there was shipped ore and bullion containing 30,558,825 oz. silver—an increase of 4,961,000 oz. over the 1909 output. Most of this came from Coleman township, while Gowganda and Elk lake together contributed 480 tons of ore, containing 481,523 oz. of silver, and South Lorrain 233 tons, containing 224,233 oz. The total dividends paid by shipping mines to the end of 1910 was $21,802,150, and to this must be added the profits of mines operated by close corporations. O'Brien and Drummond and the original La Rose company have made profits which add to the total over $3,000,000. Some of the dividend payers, noticeably Nipissing, La Rose and Crown Reserve, start the year 1911 with a very large surplus in cash, and ore shipped or ready for shipment. The production for 1911 is expected to be about 33,000,000 ounces.

The chief producers in 1910, as in previous years, were Nipissing, La Rose, Crown Reserve, Kerr Lake, Coniagas, McKinley-Darragh, Temiskaming, Buffalo, O'Brien, Hudson Bay, Trethewey and Right of Way mines. The eight companies first named produced during the year about 23,700,000 oz. of silver, or four-fifths of the output of Coleman township.

Future Prospects.

There is still much well-loacted ground which has not been carefully examined, and it will be surprising if many more rich veins are not discovered. At Cobalt it has not been found advisable to push exploration very far ahead of production, and estimates on future yield are liable to be wide of the mark. On the basis of present ore reserves and past experiences in discoveries following on development, it seems likely that in the next four or five years, if natural progress be not unexpectedly interfered with, Cobalt will produce another 100,000,000 oz. silver, at a cost permitting of large profits. It also seems reasonable to predict a further large output at costs allowing a small profit.

STUDENTS' PAPERS

LONGWALL MINING AND EMERY PIT, DOMINION NO. 10 RESERVE, C.B.*

By G. L. BURLAND, McGill University, Montreal.

The Emery seam immediately underlies the famous Phalen seam of the late Dominion Coal Co., (now consolidated with the Dominion Iron and Steel Co.). The head offices of the mines are situated in Glace Bay, Cape Breton, and all the general works of the sixteen pits are governed indirectly by the head office and directly by local managers and district superintendents. The Emery pit has changed hands several times and many attempts have been made to open up this thin seam.

Longwall mining was first introduced into Canada at Reserve, Cape Breton, where the writer gathered much valuable information through the kindness of the mine officials.

The seam varies from 4 feet to 5 feet in thickness within the Reserve area, and is from 150 to 180 feet below the Phalen, outcropping 3,900 feet to the south of the Emery shaft.

The strike of the seam is approximately n. 75° w. and along with the overlying measures, forms one of the lower beds of a synclinal basin, having the Hub seam as an axis about which the sister seams lie in concentric rings. The pitch of the seam, at the Reserve Mines is equivalent to a 7.5% grade. Two miles eastward the pitch is 6° at n. 60° w., while at 3 miles the pitch veers back northward with a dip of 10°. Tracing the contour of

*Student's paper entered for the 1910 competition and awarded the President's Gold Medal.

EDITOR'S NOTE:—Much of the information, as originally contained in this paper, including statements of costs, etc., could not be made public. The paper has also been otherwise considerably abbreviated for publication.

the seam, we find that it dips towards the Hub in a saucer shape, from which characteristic this submarine mine derives its name. The Ross or Emery seam outcrops at Schooner-Pond Cove on the east and Sydney Harbour on the west, before finally disappearing under the Atlantic Ocean. How far this seam and the adjoining coal measures extend under the sea, is not known to coal specialists. As regards possibilities of development, operations on the Emery seam are but commenced.

GEOLOGY.

A detailed consideration of the Emery seam as to the geological relations of the coal measures in which it occurs, would bring to light many interesting facts, a complete study of which would involve a thorough individual treatment. The writer has prepared several sections showing the bedding of the sandstones, under-clays, coal seam, and carbonaceous shales, to which reference will be made. The pavement or bed immediately underlying the seam is highly argillaceous, and upon exposure to the atmosphere becomes quite soft and may be used to tamp blasting powder without the addition of water. In short, this bottom is a so-called hardened fire-clay.

The seam yields a coal well adapted for domestic and steam purposes, and also to the manufacture of gas. The coal, moreover, is much harder than that of the higher seams owing to the pressure of the sandstone beds. It is easily handled and does not break so readily as the coal in the adjoining main slope of the Phalen seam.

The till or band of argillaceous shales between the carry rock and seam varies from a few inches to three feet. Thin bands of coal occur in this till. Waters stained with peroxide of iron trickled from the roof, and in places left coatings of iron oxide upon the pavement, due to the waters depositing the iron held in suspension. Many specimens of *Sigillaria*, also *Stigmaria* roots were obtained, occurring both in an erect and horizontal positions. The largest specimen of *Sigillaria*, 2 feet in diameter and 3 feet long, with *Stigmaria* roots attached, was seen in str. 5 gate, Lower North Landing.

Capping the argillaceous shales and in some instances replacing them, are carbonaceous shales. These shales also occur in the coal seam as "splint." These shales carry many distinctive fossils, so much so that the presence of the Emery seam is indicated by this band during prospecting operations. Among the specimens obtained and photographed by the writer are *Alethopteris, Recopteris, Arborescens, Neuropteris, Calamitis, Sigillaria and Stigmaria.*

Having dealt with the shales which constitute the till, we now come to the sandstone bed which overlies them, and which forms the carry rock, being the thickest of this series of strata. Samples were taken from the machine fractures in the roof, some of which were fine-grained and greenish, while others were coarse-grained and yellowish. Thin stringers of coal, or carbonized vegetable matter, were common within a range of three feet from the bottom of the sandstone. The fossil-leaves of *Calamites* and *Cordaites*, "*Annularia*" and "*Astrophylites*," *Alethopteris* and *Lepidodendra* were also detached.

The fracture, thickness and physical characteristics of all the beds will be treated throughout the paper in the order in which they lie, with reference to the advancement of the longwall face.

MINING.

Emery Slope.—In 1873 the Cape Breton Coal & Railway Company opened a triple entry slope from the outcrops of the Emery seam which was called the Lorway mine. The main deep had an east and west return airway and was driven for 1,250 feet. Bords were broken off at this point to both sections and were double entry. The slope was 10 feet wide, where single tracked, and was brushed to 6 feet in height.

As the Lorway did not prove a paying investment and a bad roof and wet pit did not warrant further expenditure, operations were abandoned in 1875; but a barrier pillar was left and the Sydney and Louisburg Coal Company ran a cross measure drift from the main slope of the Phalen seam to the Emery seam, opening up the coal beyond the barrier. At a point 245 feet from the entrance of the slope, the drift was started away on a 28 per cent. pitch and continued for 550 feet. The grade was eased off to 16% at this point for 200 feet, joining at a point below the present North Landing. They worked the coal to the rise. The mine

General Map of Workings, Emery Pit.

changed hands and the Dominion Coal Company decided to suspend operations here in 1893. The company pumped out the idle pit in 1905 and commenced the longwall face. In 1906 a shaft was sunk at a distance of 2,000 feet from the lower landing of the drift and the present pit bottom was laid out. The deeps were driven and connected on the 26th of July, 1907, with the advancing deeps from the working slope. These advancing deeps were driven at a very uniform rate.

Punchers were used to undercut the coal which was shot down and loaded by the same method as is treated later on in narrow work discussions.

6,500 feet of 15 feet (average) gangways were driven with 600 feet of 10 feet cross cuts, making 21,300 tons of coal.

The shaft and pit bottom were laid out by contract. Coal was hauled up the deeps to the shaft in July, 1907.

In 1906 the output was 100,617 tons. In 1907 the output was 163,000 tons.

STANDARD COSTS.

Work	Place	Dimensions	Standard Cost	Notes
Puncher Cutting..	Level.	20 ft. wide..	50c. ton	Cutting
Puncher Cutting..	Level.	12 ft. wide..	56c. ton	Loading Shooting
Puncher Cutting..	Deeps.	20 ft. wide..	53c ton.	Shooting
Puncher Cutting..	Deeps.	12 ft. wide..	58 5c. ton.	
Puncher Cutting..	Headings.	20 ft. wide..	52c. ton	Shooting
Puncher Cutting..	Headings.	12 ft. wide..	56c. ton	
Laying track.	Longwall Face		3 5c. ton	Contract
Laying track.	Levels.	18 lb. rails..	21c. yd.	Datal
Laying track.	Deeps.	30 lb. rails..	25c. yd.	Datal
Timbering	Deeps.	Booms and 2 props.	25c.	
Timbering	Deeps.	9 ft. booms.	40c.	Needled
Timbering	Deeps.	9 ft. booms.	60c.	Needled

THE EMERY PIT.

To facilitate the pursuance of the following detailed sections of the pit, the writer would introduce a skeleton outline of the workings. The main level feeds directly to the shaft bottom at an angle of 120 degrees to the newly connected traverse level joining the south deeps at their face. At a point on the main level, 250 feet from the shaft, the deeps break away to the right in a direction forming an angle of 70 degrees with the pit bottom level, or main level as termed in practice. The present face of the deeps is 2,500 feet below. At a distance of 900 feet the new landing breaks to the left from the deeps parallel to the main level. Still 800 feet further down the deeps, the Lower North Level breaks to the left parallel to the New Landing, and south deeps break to the right at an exterior angle of 160 degrees. The south level continue for 1,700 feet and join the traverse level before alluded to. Work on the face ceased September 1908, when the barrier necessary for the French slope was reached.

THE PIT BOTTOM.

Due to the pressure of the roof causing creeps, great care is exercised in laying out the Pit-bottom pillars.

The main deep tubs and the high side tubs (those from main level) feed to the shaft bottom around a curve.

The landing is 45 feet long by 18 feet wide and is double tracked, the cross switches from south deep traversing level, main deeps, and main level. The switch from the latter two consists of a throw block, which feeds the boxes consecutively to both compartments of the shaft. The tub lines, timbering, and handling of the boxes will be treated in later sections.

The method employed in opening the longwall face was as follows:—Nos. 1, 2, 3, 4, 5 and 6 gates were driven for 75 feet, leaving barrier pillars to support the entry. Face opened by crosscut driven by punchers and worked towards the rise, the coal being undercut by a rotary disc undercutter made by the Diamond Machine Company. As the face progressed, it worked towards the north and at present has reached the 16th gate. The gates were spaced 50 feet apart up to No. 6 gate, but from this point to continue at 80 feet. No. 1 gate serves as 1st machine stable on the south end of face, and each successive gate as it is driven serves the same purpose for No. 4 machine on the north end. No. 2 gate was carried forward 75 feet from entry pillars, and cross gate turned off to left at an angle of 50°. This reduced the grade of the cross-gate by running at nearest possible approach to strike

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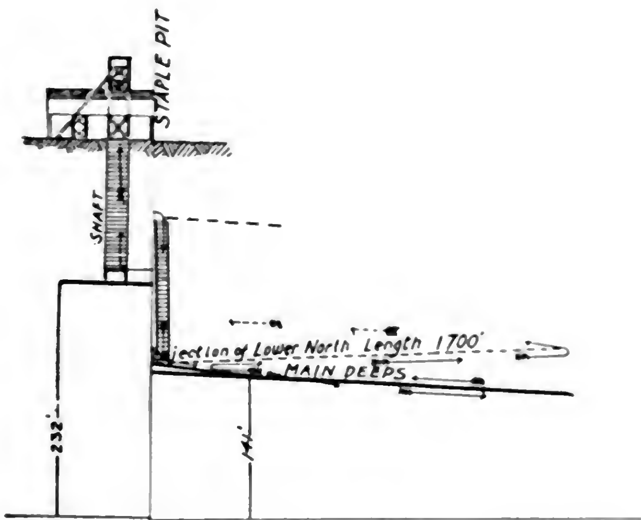

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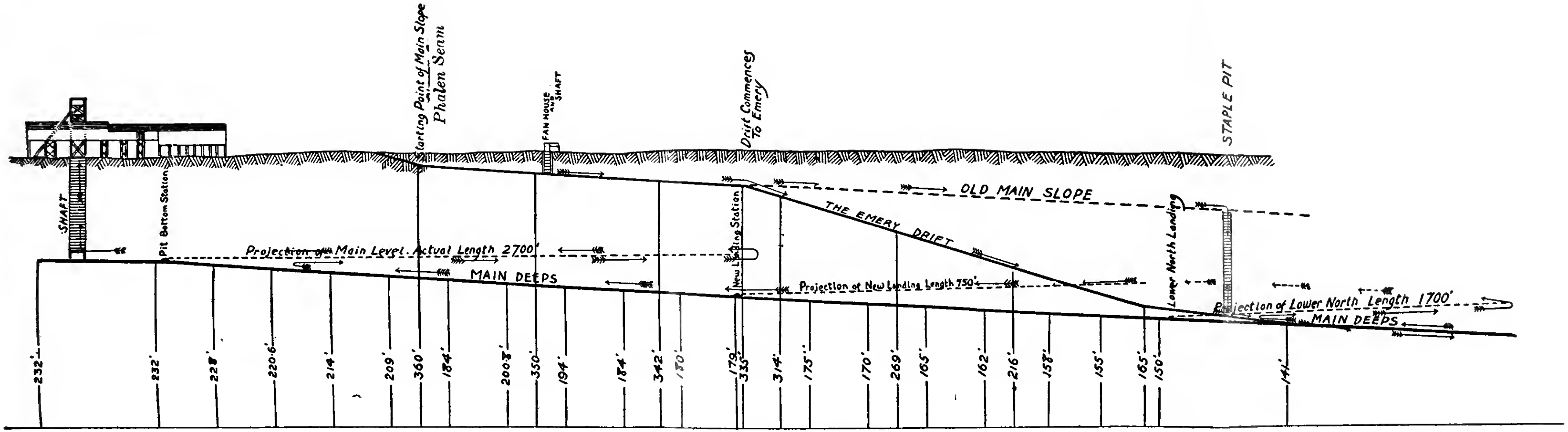


Profile, General Workings.

of seam. 50 feet up this cross-gate, a cross-gate was broken off to the right which is termed "1 off 1 to left of 2." Now head of No. 3 gate was parallel with this gate and its cross-gates, so No. 1 to left of 3 was started out and coal was drawn from stalls of No. 2 gate by this new road. Similarly 1 to right of 3 cut off No. 4 gate. Throughout the workings, this process was continued and accompanying table shows the gates, their lengths and cost of maintenance. It can be seen that it would be unnecessary expense to keep No. 2 gate in repair when the coal could be drawn by No. 3 gate. The gates are designed to meet the face at from 75 to 100 feet apart.

The average grade will be assumed to be 7.5%, which corresponds to pitch noted in several gates. It is difficult, of course, to extenuate the actual pitch without a complete survey, owing to the creeps formed by pack walls squeezing pavement up into the roadways.

The cost of maintenance of the roads to such date as the respective gateways were abandoned, is given in table below:—

Gate	Length Crossgate	Working or Abandoned	Face Brushing (cu. yds.)	Back Brushing (cu. yds.)	Cu. yds. of Pack Walls
1	650	Used as stable	....		925
2	450	Closed	601	1,328	1,072
3	1,200	Working	1,594	4,169	3,302
4	350	Closed	466	977	815
5	425	Working	566	1,246	1,038
6	300	Closed	289	801	678
7	425	Working	566	1,246	1,038
8	300	Closed	289	801	658
9	250	Working	334	623	517
10	900	"	1,195	2,925	2,441
11	250	"	240	615	518
12	300	"	289	801	658
13	250	"	240	615	518
14	200	"	267	454	369
15	150	"	145	267	273
			7,655	17,868	15,100

Rated Cost	Cu. yds. x cost	Cost
Face Brushing at $1.13 cu. yd.	7,655 x $1.13	$ 8,650.00
Back Brushing at $1.21 cu. yd.	17,868 x $1.21	$21,620.00
Tramming & Packing .60 cu. yd.	17,868 x $0.60	$10,720.00
	Total Cost:	$40,990.00

Area of coal extracted = 1,120,000 sq. ft. seam 4 ft. thick = 224,000 tons (5 x 4 x 1 very approx. = 1 ton).

Now 3″ of seam is lost as "duff" or fine slack cuttings from holing by longwall machine = 14,000 tons.

5% of remainder lost (bench and crushes) = 10,000 tons.

Good coals drawn = 224,000 — 24,000 = 200,000 tons.

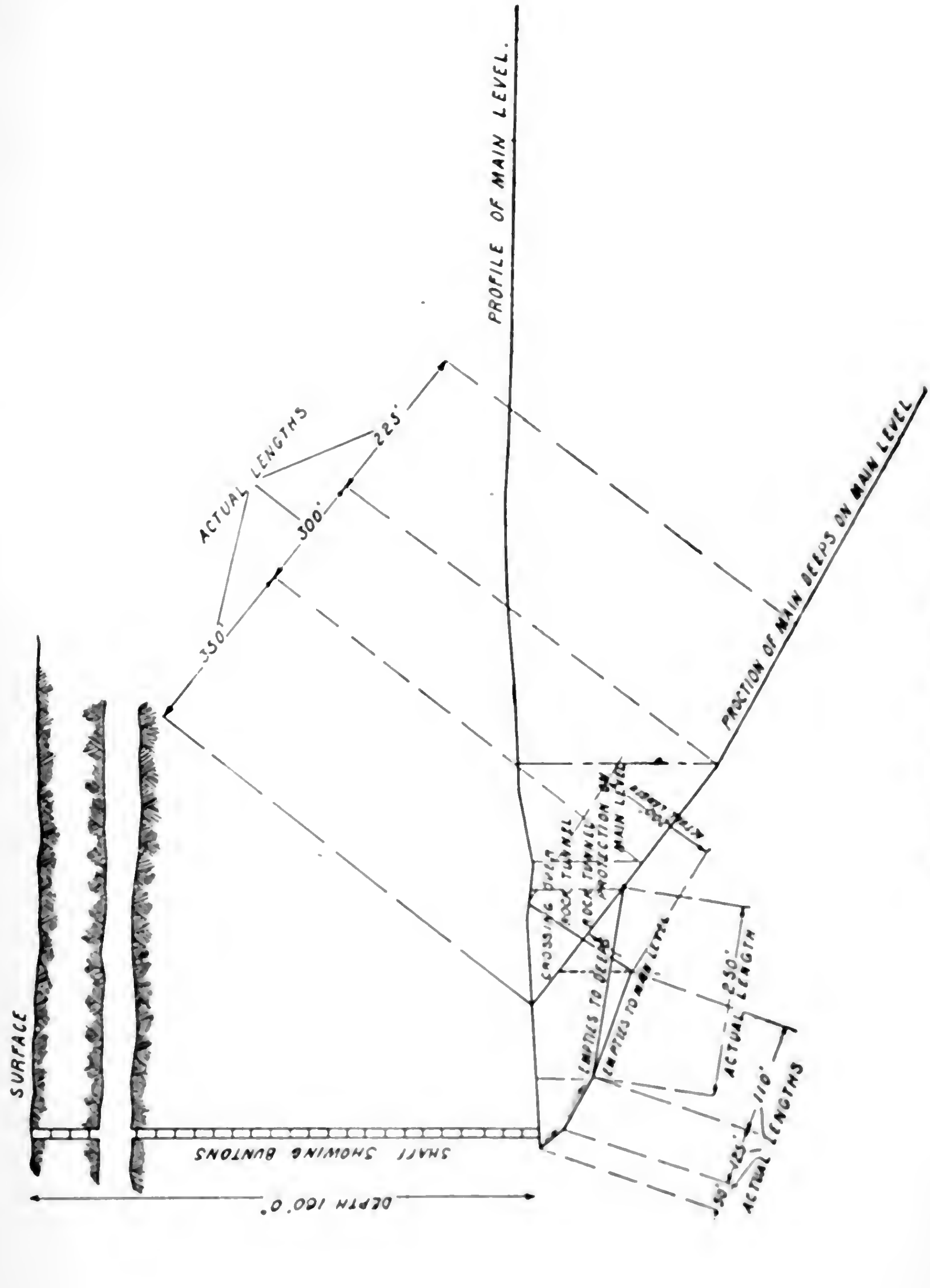
∴ Brushing per ton = $40,990.00 = 20.4c.

200,000

This is a very close approximation to Company's figures. The calculation above were worked out from general plan and the following standards.

Work	Standard Measurements	Cost per Standard	Cost per cu. yd.	Average Thickness Assumed	Cost per Thickness
Face Brushing. . . .	9 ft. wide, 3 ft. long, 1 ft. high	1.13	1.13	4	4.52
Back Brushing. . . .	12 ft. wide, 3 ft. long, 2.5 ft. high	4.00	1.21	8	9.68
Tramming and Packing. . . .	12 ft. wide, 3 ft. long, 2.5 ft. high	2.00	0.60	8	4.80

The New Landing and Lower North Levels were driven 550 feet apart. This whole district may be subdivided into three workings, two of which are joined, and the third worked out. The Lower North level being part of the original opening developments, it will be discussed before joining the New Landing face 19/11/09. The third or corner district was drawn by gates 1 and 2 of L. N. These gates and their cross gates fed to deeps indirectly through a heading or road almost parallel to main plane of coal (20° to



Emery Pit, Profile of Main Level Workings.

west). This heading extended to New Landing where three additional gates fed to that level.

The gates were connected by a face gate driven from No. 2 gate in a direction 42° south of west and meeting 5 cross gate to right of 1. Work was discontinued shortly afterwards.

For comparison, the writer has compiled the following tables and would give a brief note on the method employed. No official figures were available for any tables, and all tables have been deduced from the working map of the mine, a reduction of which, with total available data, is illustrated by the general plate of the workings. The object of the following comparisons is to emphasize the study of correct angles, and spacing of these gates per ton of coal extracted. Plate 9 is divided into districts of progress, and the dates worked out by average proportion from several survey dates recorded. A previous statement shows 6,400 feet of gates and cross-gates having 7,655 cubic yards of face brushing and 17,868 cubic yards of back brushing. One foot of gateway costs $6.00 (approx.). In the following case $3.00 has been deduced as standard owing to the number of gates which were abandoned before back brushing became necessary.

District	Date of Survey	Total ft. advance	No. days taken in advance	Ft. per day advance	Date of Survey deduced
A–C.	9/11/08				
	7/29/08	150	232	1.54	
A–B.	22/ 1/08	50	74	1.54	22/1/08
B–C.	29/ 7/08	100	158	1.54	
C–D.	19/ 2/09	150	205	1.40	
D–E.	1/ 4/09	25	41	1.60	
E–F.	7/ 7/09	50	99	0.50	Note "Lagged"

District	Planimeter Readings	Total Area in sq. in.	Total No. tons in District	Duff 5% waste of Coal
A–B.	2 —1.49	3.49	6,980	780
B–C.	66.77—1.0	7.77	15,540	1,756
C–D.	13.6 —9.4	23.00	46,000	5,198
D–E.	1.5 —2.76	4.26	8,520	963
E–F.	2.1 —4.4	6.5	13,000	1,469

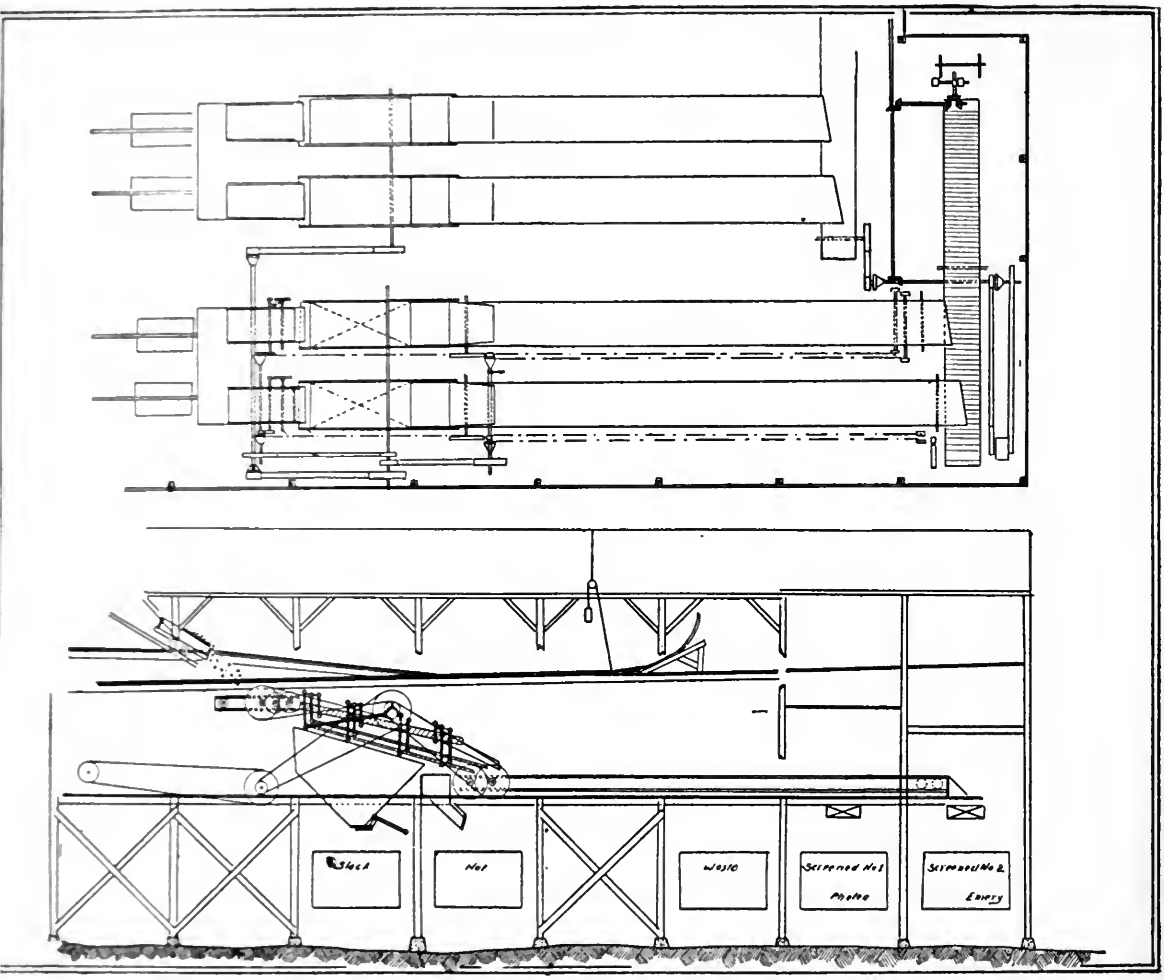
District	No. of Days	Total Coal extracted	Aver. Coal per Day	Length of Gateways	Length per 100 tons	Brushing per ton
A–B.	74	6,200	83.8	750	12.1	0.36
B–C.	158	13,784	87.2	1,700	12.3	0.37
C–D.	205	40,802	199.0	3,600	8.82	0.26–1/5
D–E.	41	7,557	184.3	650	8.6	0.26
E–F.	99	11,531	114.3	950	8.2	0.24–4/5

Thus at $3.00 a foot we see that from 9/11/08 to 7/7/09, a decrease has been brought about per 100 tons of $11.20 or 11.2c. per ton in brushing. At such a speculative stage in the Emery's history, this reduction is of great value. A further reduction of a few costs is possible.

After repeating these calculations for the New Landing section, the writer intends to reconsider this level and will compare the cost per ton with 80 feet stalls, to the older system of driving the gates, giving 40 feet stalls.

District	Dates of Survey	Planimeter "sq. inches"	Total No. of tons in Dist.	Duff 5% waste	Total Coal Extracted
A.	9/11/07	....	....	....	.
A–B.	22/ 1/08	4 sq. in....	8,000	904	7,096
B–C.	29/ 7/08	6 in. sq....	12,000	1,356	10,644
C–D.	19/ 2/09..	13.57 sq. in..	27,140	3,067	24,073
D–E.	1/ 4/09	4 sq. in....	8,000	904	7,096
E–F.	7/ 7/09	6.4 sq. in..	12,800	1,446	11,354

District	Length of Gateways "A"	Length per 100 tons "A"	Brushing per ton "A"	Length of Gateway "B"	Length per 100 tons "B"	Brushing per ton "B"
A–B.	675	9.5	0.31c.	470	6.6	0.29c.
B–C.	1,150	10.8	0.32c.	750	7.1	0.21c.
C–D.	2,000	8.2	0.39c.	1,625	6.9	0.32c.
D–E.	500	3.5	0.33c.	475	3.5	0.31c.
E–F.	625	5.5	0.26c.	625	5.5	0.26c.



Screens and Picking Tables, Dominion No. 10.

A—Gates spaced for 40 ft. stalls on face.

B—Gates spaced for 80 ft. stalls on face.

To derive an average standard for A, and B, the writer takes total gateways in case A at 4,950 feet, abandoned gates 1,450 feet, or 3,500 feet of gateways requiring back brushing.

3,500 feet at $6.00	=	$21 000.00
1,450 feet at $1.80	=	$ 2,610.00
4,950 feet	=	$23,610.00
1ft.	=	23,610 ÷ 4950 = $4.80

Thus 675 feet of gateways at average of $4.80 = $0.31 per ton. An exception to the above rule is made in this case and the standard lowered to $3.00 owing to the greater percentage of abandoned gates. The standard used in Lower North is substituted in this instance.

The New Landing works were driven to the rise from the level and so continued. The level was driven for 800 feet and a drift was started away meeting the second left-hand cross-gate off No. 5 Long North. There are four working gates relieving the numerous cross-gates from the face. 50 feet up No. 1 gate, 1st x gate to L. was broken off and driven parallel to the deeps 25 feet from the end machine table or return air course. This gate is 550 feet long and will continue for 150 feet when the main level barrier will be reached. Average advance per day (reckoned on time to drive a certain distance, not per shift) is 1.54 feet, or face will reach the boundary in 90 days. The longwall machines will then be moved along the extending face of the Lower North.

On 9/2/09, the New Landing workings were connected to those of the Long North. Gradually the face was straightened until at present date one continuous face extends for 2,700 feet.

As before stated, the south level was driven to the south from a point on main deeps opposite to the Lower North. The level, as this section of the deeps should rightly be termed, extended 1,200 feet, when work was discontinued on the face at this point owing to the French slope barrier being reached. A résumé of calculations similar to those just deduced in the workings to the north of the deeps, brings to light a more systematic layout of the gates. Total reading by planimeter is 26.8 square inches of coal worked or 53,600 tons of coal worked, giving 47,430 tons of round coal. There are 2,680 feet of gateways, making 0.1 foot per ton of coal. Assuming the same standard of $3 a foot (all told) gives 30 cents a ton for gate maintenance.

The traverse level is a continuance of the south deeps under the Phalen slope barrier. A cross cut connects this section to the double entry level started away to the east from the shaft station. Water drains from these workings to lodgement at Lower North. A discussion on the dams will be found in connection with the pumping section.

DETAILS.

Longwall mining has the advantage that a large percentage of round coal is drawn at a very low cost. The coal is easily drawn and is safer to work than the room and pillar system. As a rule the loss of the coal through machine "duff" is very low, but decreases in percent indicated by the following original formulæ deduced from observations by the writer.*

Percentage loss in any seam is. . . . . $\frac{100\,A}{N}$

Where $N = \frac{M}{X}$, or formula written. . . . . $\frac{100\,A\,X}{M}$

A = Max. loss when working 18″ seam = $\frac{1}{6}$ (a constant).
N = Multiple of seam with respect to 18″ seam.
M = Thickness of seam under discussion in inches.
X = Thickness of standard seam or 18″.

Applying this formula to the Emery:

100 x $\frac{1}{6}$ x 18/48 = 55% of coal wasted as machine cuttings or "duff." This formula is recommended to estimate the advisability of cutting coal by hand or by cutting machines. A loss of 8% would be a maximum, therefore the smallest seam in which the longwall cutter should be used can be calculated from same formula.

$$\text{No. } 8 = \frac{100\ AX}{M}$$

$$\text{No. } 8 = \frac{100 \times 18}{6\ M}$$

$$\therefore\ M = 32.5''$$

Say 30″ or 2.5 feet for minimum thickness.

This point is strongly emphasized as the gates are spaced according to the coal area and not to the round coals drawn. Every ton lost means that although it receives its portion of the general dissection of mining costs, it is of no value to the company. Illustrating in case of a 10% loss from "duff" with respect to one item of mining operations, namely brushing, shows:—Taking average per ton brushing = 30 cents, total losses as 10% "duff" 5% general waste, and calculating for 100 tons (arbitrary) basis,

* Note.—In reference to English methods of cutting in 18″ seams the conditions as suggested by Canadian practice are used.

costs $30.00 in gate maintenance. Under ideal mining conditions 115 tons should have been mined, bringing brushing to $\frac{3,000}{115} = 26$ cents a ton. This clearly shows the percentage reduction in costs for one item. With reference to the Emery, 110 tons should be mined for ideal conditions, giving brushing 27 cents a ton. When considering the total costs, it should be remember that every percentage of coal wasted increases the aggregate account per ton of coal; hence we cannot afford to have our "duff" rate too high.

The Diamond coal-cutter, built in two sizes for the company, consists of a crucible steel double segment wheel carrying ten blocks which hold three picks apiece. This wheel is supported by a horizontal steel bucket called a butterfly which is attached to the main frame of the machine by four bolts. These bolts may be loosened and both the wheel and butterfly disengaged to facilitate the removal of the machine to other parts of the workings. The wheel is driven by a pinion geared into slots upon the upper side of the segments. The pinion derives its power from a forged steel crank shaft driven directly from two cylinders, one of which is situated at each end of the machine. This last point is of great importance as the writer noted while working with the Diamond cutter, inasmuch as it is equally balanced and equally strong at both ends to withstand severe crushes of rock and coal. In contrast, the Gillott & Copley coal-cutter is pointed out, having both cylinders at one end, with the crank shaft at the other. A fall of rock upon this unprotected shaft is likely to disable the machine for a considerable time.

The machine derives its forward or reverse motion from a drum on one end of the frame. This drum is driven by reducing gear wheels connected by a rod to a speed regulator geared to the crank shaft. A rope of $\frac{1}{4}$ inch diameter passes through a block fixed to a rail by a "D" bolt. This rail is carried out the full length of the rope, and one end of the rope being fixed to a bridle, and the other end to the drum, the machine drags itself forward when the ratchet motion is thrown in by means of a clutch. Air hose can be attached to either end of the machine by means of "spuds" into the valve gear. A removable throttle or key is used to prevent accidents. The machine can move in either direction by altering the eccentric gear.

The detailed method of driving the face is as follows:—A row of machine timbers are spaced a pick-handle and a half from the face and 5 feet apart. These timbers hold the rotary disc cutter to the face. The rail is carried forward with the propelling rope and a notch cut in the roof or coal (see Plate 12). The machine cuts at a rate of 0.75 to 1 foot a minute. Two shiftmen go ahead of the machine and take up the bench, at the same time scraping the pavement and trimming the overhang of the coal face. This overhang is due to the carelessness of the coal hewers who do not place their shots correctly. The shiftmen are required to test the roof and props, putting in booms nitched into the face when required for safety.

It is suggested that these shiftmen or "trimmers" should reach the face at least two hours before the back shift and have the work checked out for them. They should couple the hose to the machine and have sufficient clearance for the machine to run without being blocked. The writer has seen a machine buried and left from the last back-shift and by the time it was uncovered, hours of cutting time would be wasted. Under the present system the machine man and his helper have very often to help the shiftmen clear.

Each machine cuts from stable to stable and then returns. Thus on main level No. 1 machine cuts from end of face nearest shaft to 1 cross-gate to R. of 3; No. 2 from this gate to left-hand cross-gate off 10; No. 3 machine to straight 10; and No. 4 machine to the north end of face.

The coal must be drawn from gate to gate as near the turning point of machine as possible. If small blocks of coal are left, they are heaved back into the gob and are not recovered. The writer has been compelled to shovel several boxes in one night. The hewers are careless about lifting the bench or layer of coal left between the underside of the cutting segments and pavement. This coal is hard and is sometimes 5 inches thick. If near a gate, it is heaped pending loading by the next fore-shift. If past the pack walls, this coal also goes into the gob. This bench necessitates having two shiftmen whereas in most cases one man can handle the timbering and clear away the fallen "till."

The coal after being "kirved" or "mined," which by-the-way is often almost omitted, should be nicked. The writer has noted a man firing four shots without detaching as much material as a good miner would fall in one shot. In the Emery, this is done at the head of the gates and the coal shot down to the right and left.

HAULAGE.

The underground transportation is effected by horses and mechanical devices. Small Newfoundland ponies draw the cars from the face to the main coupling sidings or directly to the pit bottom.

A special feature worth noting is the Lower North level where a tail rope system is employed to pull its trip to a spare road or "flat" past No. 5 gate. Two pull wheels are situated at this gate and another auxiliary rope may be attached to the head of the trip and the cars taken to a flat near the working face. Horses draw to the upper spare roads and exchange full tubs for the incoming empties.

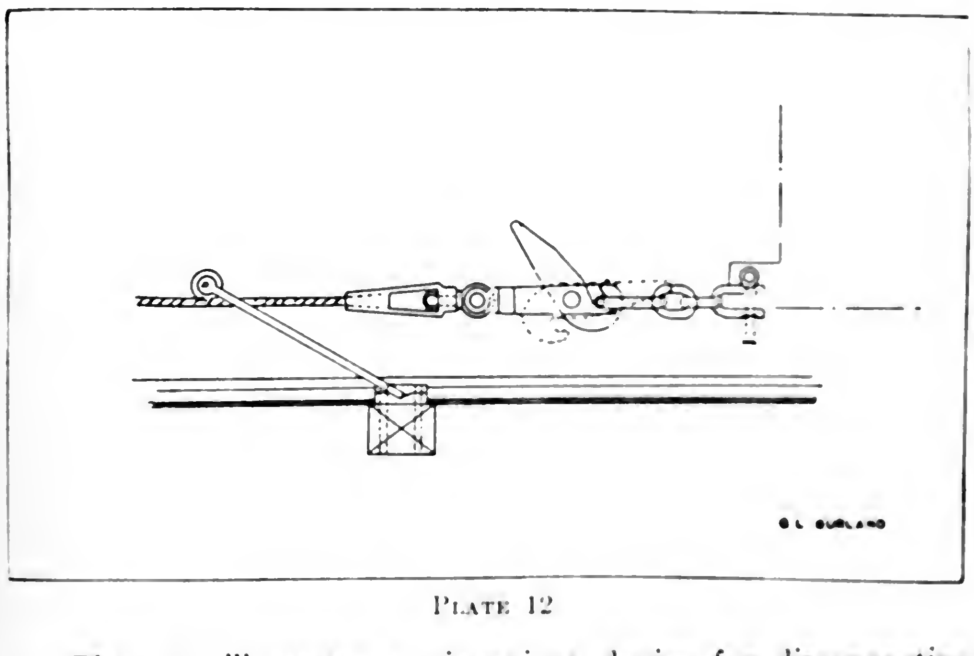


PLATE 12

Plate 12 illustrates an ingenious device for disconnecting the head rope on the outbound trip. The tubs gain sufficient momentum from the grade to allow them to run past the double drum donkey and out to the main coupling station of the deeps.

The rope acting as a tail rope on the inbound trip is passed under the roller and when the roller passes over the socket, out bye, the clutch is thrown as indicated by the dotted sketch.

The main haulage rope is driven by a Corliss Engine, which also operates the French slope rope. This engine has a 20′ x 60′ cylinders and runs at 60 revolutions per minute. The rope passes down a bore hole lined with piping to head of deeps. Another counter-balance takes care of the slack underground and is situated down the deeps. Tubs are coupled to rope by a method described in the paper of E. P. Cowles to Canadian Mining Institute (1909 competition), so the method will not be touched on in this discussion.

The mine cars are 6 feet 4 inches long, 2 feet 8 inches from rail to top of box, and 3 feet 6 inches wide, weighing 850 lbs. when empty.

THE ALEXO MINE.—A NEW NICKEL OCCURRENCE IN N. ONTARIO.*

By W. L. UGLOW, School of Mining, Kingston, Ont.

An interesting deposit of a nickel ore was found in Northern Ontario three years ago by an old prospector, named Alexander Kelso. Little attention has so far been given to this occurrence by geological and mining periodicals; attributable no doubt in part to the all-absorbing interest attaching to other recent finds of valuable ores in North Ontario. The ore-body was first noticed during the rush of prospectors in the Night Hawk Lake district in 1908. Several claims were then staked by Kelso in the immediate vicinity of the deposit, while more sanguine prospectors were apparently satisfied with staking the remaining areas of an otherwise practically barren township.

The Alexo Mine, as the ore-deposit has been named, is situated in Concession III, Lot I, of Dundonald Township, near the boundary of Clergue. Figure I shows the position of the mine, relative to the Temiskaming and Northern Ontario Railway, and to Porcupine. The heavy line in the sketch running west and south of Dundonald, and east of German and Macklem marks part of the eastern boundary of the Porcupine Mining Division, while Porcupine townsite is indicated at the south-west corner of the map. Kelso Mines, commonly known as "Mileage 222," the "jumping-off place" for Porcupine, is 4½ miles to the north-east of the mine; and, as shown in Figure II, an old winter road from Kelso Mines to Porcupine passes within a few yards of the workings.

The general appearance and relief of the country does not suggest the presence of ore-bodies. It is part of the "clay-belt"

* Students' competition, 1911, awarded President's gold medal.

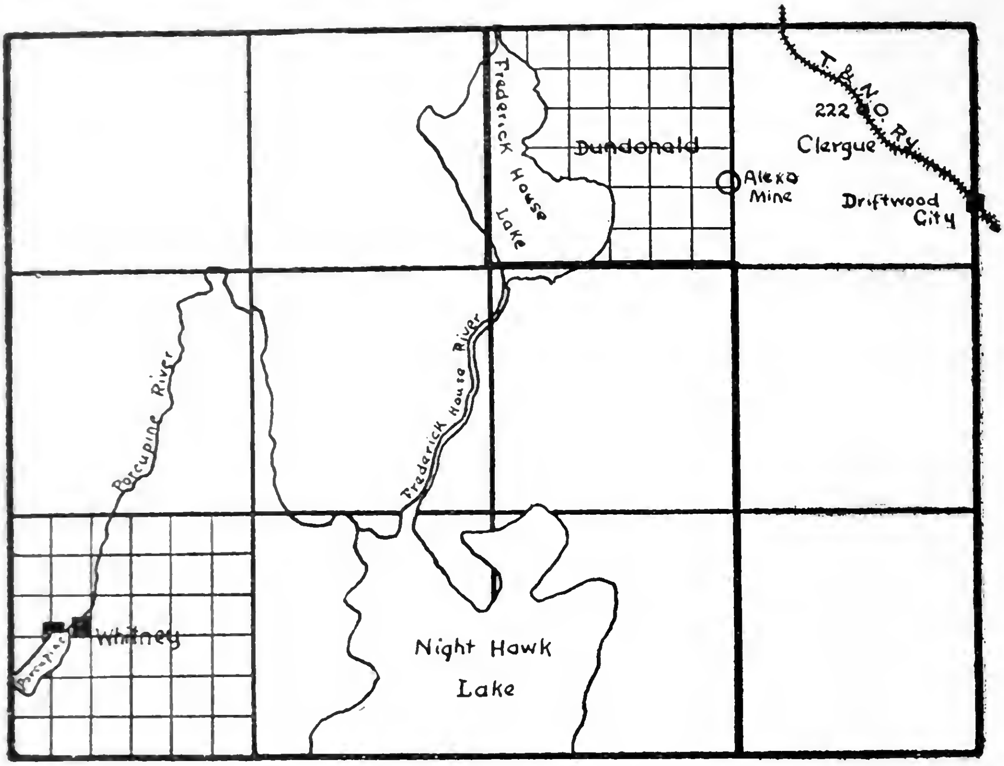


FIG. I.

and shares its well-known characteristics. Frederick House Lake, some three miles to the west, lies in a very shallow depression and in midsummer it is fordable from shore to shore. The land for a distance of a mile and a half to two miles from the lake is a rolling clay loam, thickly timbered with poplar, birch, spruce, balsam, etc. As shown in Figure II, this is succeeded by a notably flat sand plain extending from the north. To the south and east of the sand plain are found the only rock exposures of the township, with the exception of a fringe bordering the promontory on the east shore of the lake, and an island immediately to the south of this. Concessions I, II, III, Lots 1, 2, 3 Dundonald, and the western part of Clergue, contain the main body of the rock mentioned. This small area has slightly more relief than the surrounding districts, and the rock exposures occasionally rise in a sheer wall to a height of nearly one hundred feet. Figure II shows in a general way the surface geology of the district.

OCCURRENCE OF THE ORE GENERALLY.

The ore-body, so far as ascertainable by surface inspection, is of small extent. It occurs on the north-west side of an exposure of "andesite" * measuring about 700 feet by 900 feet. This rock rises on its north and west sides rather steeply to a height of about one hundred feet out of a flat swampy country, but slopes away somewhat gradually to the south and east becoming more and more drift-covered. The vertical cross-section (Fig. III) from the north-west to the south-east shows well the position of the deposit.

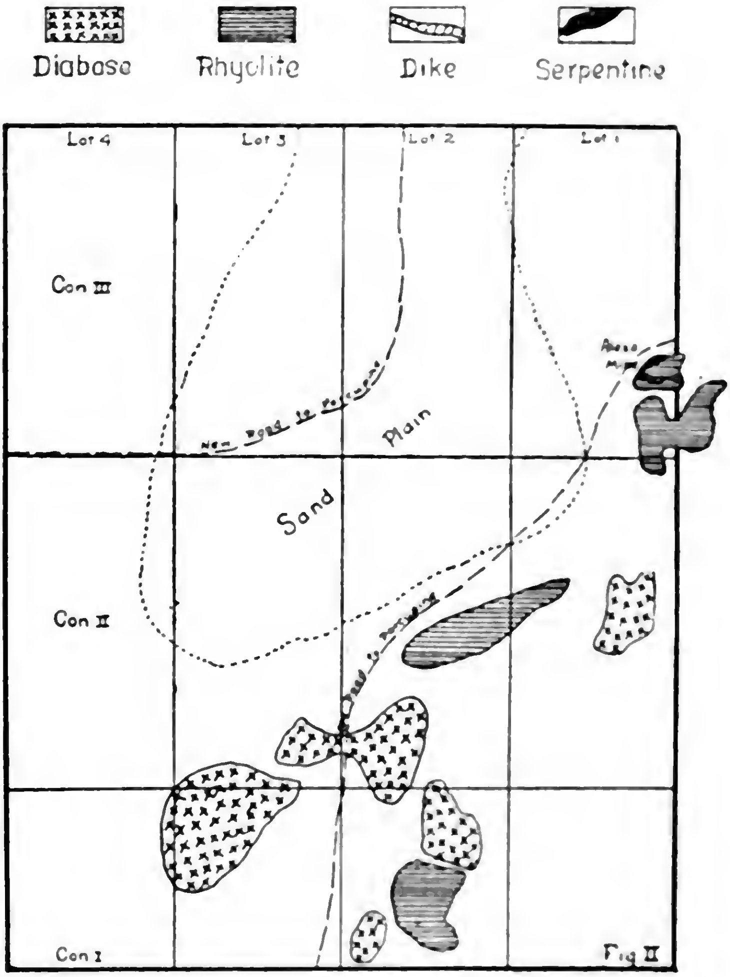


FIG. II.

The steep face of "andesite" descends some seventy-five feet or so to a terrace which, at the foot of the cliff, is still about twenty feet above the level of the swamp. This terrace is largely drift-covered, but shows here and there exposures of "andesite." It extends about twenty or thirty feet north-west from the foot of

* So-called by Dr. A. P. Coleman, "The Alexo Nickel Deposit," Econ. Geol., Vol., No. 4, p. 373.

the cliff. At this point, the rock presents a regular face sloping at about 60° into the ground. Against this face or wall, a basic rock called "serpentine" * is found. Only about ten or fifteen feet of this are apparent, the rest of the mass being hidden beneath swampy drift. The ore is found, as indicated in the sketch, along the contact of the "serpentine" and "andesite."

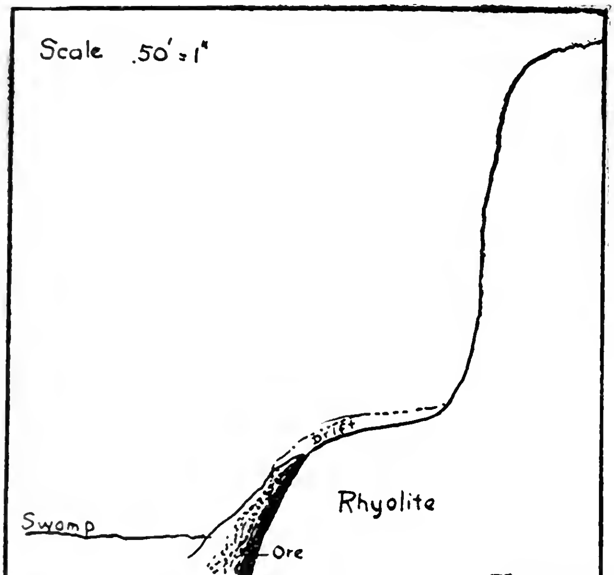


Fig. III

The relationship of ore to rock is evident only in three places namely, at the pits marked A, B, C, in Figure IV. The contact for the remainder of the distance is drift-covered.

These pits were excavated by the Canada Copper Company, which held an option on the property some two years ago. The main pit, marked A, is at the most northerly point of the deposit, but it is unfortunately filled with water. A photograph of this pit is shown in Plate I. Against the "wall" is roughly five feet of almost solid ore which then grades into "mixed" ore and basic rock. This "mixture" continues for about four feet, with less of the ore and more of the basic rock as constituents, to the edge of the swamp, and no pure serpentine can be seen here. At Pit B, these conditions are duplicated except that very little sinking has been done. At Pit C, however, solid ore is very scarce even against the foot-wall, and the "mixture" of pyrrhotite-serpentine rock, lies close against the "andesite." Here at a short distance

*So-called by Dr. A. P. Coleman, "The Alexo Nickel Deposit," Econ. Geol., Vol., No. 4, p. 373.

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Plate I.

from the wall the ore practically disappears, and a pure serpentine rock may be seen, containing small stringers of asbestos.

A considerable quantity of promising ore has been taken from the pits. On megascopic examination, the ore seems to be mainly pyrrhotite with here and there some chalcopyrite, which chiefly occurs very close to the foot-wall. The whole ore-body as revealed by the development work is not more than two hundred feet long, but it is quite possible that further stripping along the contact will expose additional ore.

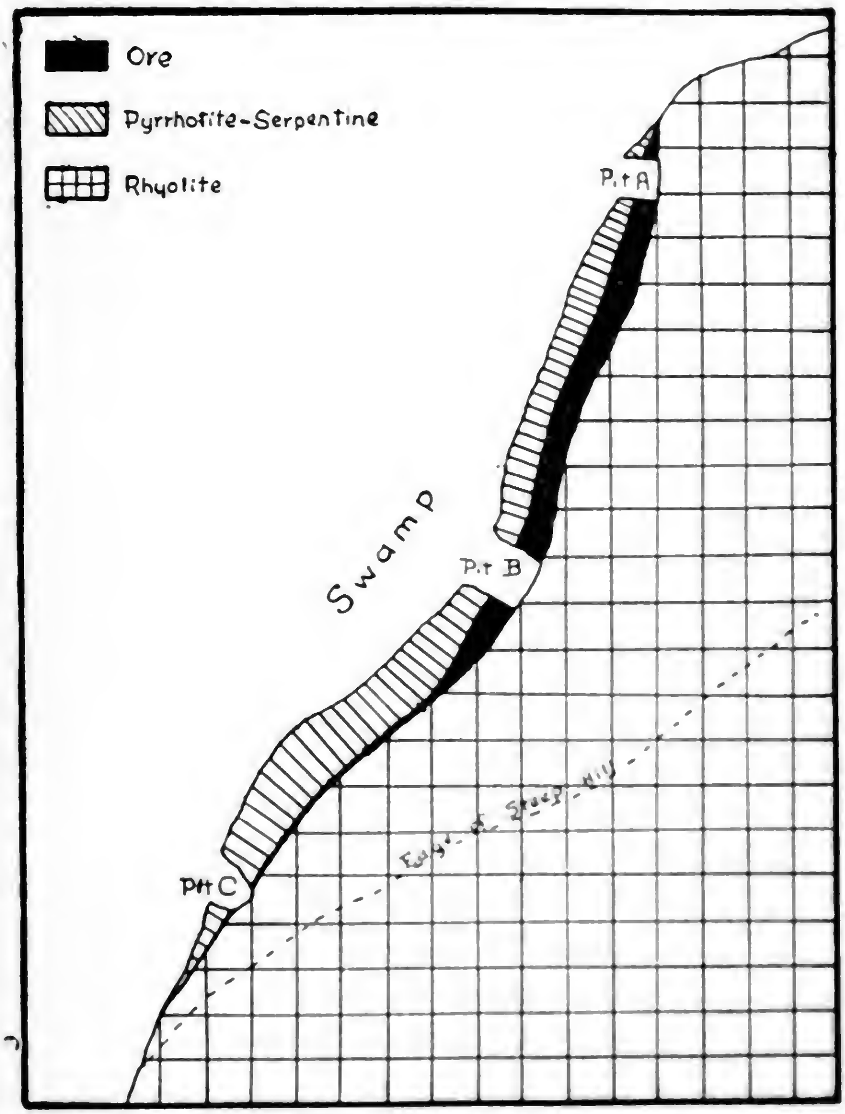

Figure IV

III. PETROGRAPHY.

It is a matter of much difficulty to work out the field relationships of the rocks of the district. Figure II shows the exposures, but unfortunately contacts are rarely to be seen. For some reason or other, these are usually drift-covered. In most cases, it is necessary to rely on megascopic and microscopic characteristics for the determination of these relationships.

(a) *Serpentine.*—The oldest rock in the district is probably the so-called "serpentine." Along its contact with the "andesite" as exposed at the time of examination, no phenomena were observed that would lead to an establishment of the age relationship of the two rocks; but it is quite likely that in this case, as in other similar ones in the north country, the acidic series of the Keewatin cuts the basic. The only exposure of the serpentine found in the township occupies the low ground close to the pits at the Alexo Mine.

Under the microscope, sections appear light in colour, and are readily seen to consist in the main of four minerals. (1) Olivine:—Pseudomorphs of serpentine after olivine, spotted profusely with black iron oxide particles, the results of the decomposition of the olivine, are everywhere abundant, and make up most of the mass of the rock. Rests of olivine are frequently seen in the centres of the crystals, and the process of alteration has been taking place chiefly along fractures in the crystals. The particles of iron oxide are found especially in these fractures. (2) Diallage:—Surrounding the pseudomorphs is a greenish gray mineral, showing aggregate structure, which is also almost completely changed to serpentine. Frequent rests of only partially altered mineral are found, and these show fibrous structure, interference colours and extinction angles of diallage. This mineral is allotriomorphic in its relation to the olivine. (3) Biotite:—Some sections show a noticeable amount of biotite, of green and brown colour, exhibiting marked pleochroism. This mineral occurs in shreds and flakes, and is usually stained with brown oxide of iron. It is closely associated with the diallage, and occupies part of the space between the crystals of olivine. (4) Chromite:—Apparently the earliest crystallization from the magma was a brownish black mineral occurring entirely in small octahedral crystals. (Plate II, No. I.)

Upon examination, it proves to be chromite, and in some sections hundreds of these small crystals may be counted. In some places the whole of a section seems to be made up of the serpentine pseudomorphs, with chromite crystals, embedded in a fine-grained indeterminable matrix, which itself has changed entirely to serpentine.

Sections taken from the rock closer to the ore-body show the same mosaic of olivine crystals, but here they are set in pyrrhotite. The ore bears the same relation to the crystals as the altered diallage and fine-grained matrix in the sections of the pure rock. In these portions of the rock which are now solid ore, outlines of crystals are still visible, marked by the presence of the darker-coloured magnetite.

From the foregoing description, the serpentine seems to have had an original composition resembling closely wehrlite (feldspar-free olivine-gabbro, with olivine, diallage, and some brown hornblende). The chemical constitution, however, as given below, seems to indicate a closer connection with the related group of harzburgites (feldspar-free olivine-norite, with olivine, and orthorhombic pyroxene):

	I.	II.	III.	IV.	V.
SiO_2	35·33	35·05	35·67	38·62	41·43
TiO_2	......	0·50	.....	...	.....
Al_2O_3	4·04	0·73	2·98	4·72	0·04
Cr_2O_3	1·65	6·72	0·87	...	0·76
Fe_2O_3	6·00	9·05	6·04	6·67	2·52
FeO	3·40	5·08	4·95	6·27	6·25
MnO	....	....	0·11	0·81	....
NiO	0·59	....	.....	....	....
MgO	37·31	33·09	35·03	29·60	43·74
CaO	...	0·54	0·18	4·61	0·55
Na_2O	......	}			{ ....
K_2O	......	.... }	0·77	1·20	{ ....
H_2O	{ 12·30	{ 8·47	12·04	7·68	4·41
CO_2	{	{ 1·54	....	......	0·10
Total	100·62	100·77	100·01	100·18	99·80

I. Serpentine from Alexo Mine.

II. Serpentine from Lake Abitibi, H. T. White, Can. Min. Inst., Vol. XII, 1909, p. 594.

III. Harzburgite serpentinisirt, Radauberg bei Harzburg-Rosenbusch, Elemente der Gesteinslehre, p. 165.

IV. Wehrlite, Frankenstein bei Eberstadt, Odenwald—Ibid., p. 165.

V. Harzburgite, Douglas Co., Oregon, U.S.A.—Ibid., p. 165.

(b) *Rhyolite.*—In contact with the serpentine, and probably intruding it, is an exposure of the rock called "andesite." It occurs throughout the township in irregular hummocks, and usually attains a respectable height above the ordinary level of the land. In many places it exhibits several of the characteristics of an ancient flow rock, and examples of ellipsoidal weathering are not uncommon. It varies in colour from a very pale gray to a grayish-green, but thin slices chipped from a hand specimen are quite translucent and show that the dark colour when present is not an evidence of basicity. To the naked eye, the rock is exceedingly fine-grained and of a very homogeneous nature, strongly resembling pieces of chert, or fine-grained quartzite.

Under the microscope, the rock appears to have been somewhat of a porphyry, both the phenocrysts and the base being made up almost exclusively of acidic minerals. Under one nicol, sections appear white, with only here and there small traces of dark minerals. Outlines of original colourless crystals can be clearly distinguished against the ground-mass which is not quite so clear. Some of these crystal outlines are still well-preserved, and have a hexagonal shape while others are somewhat worn or broken resembling fragments. With crossed nicols, a few of the crystals are still nearly perfect, but by far the majority of them seem to have been very severely fractured. Wavy extinction is very common. The matrix is exceedingly fine-grained and seems to be almost wholly of quartz-feldspar composition. The phenocrysts are sometimes quartz and sometimes orthoclase. The crushing and fracturing noticed in the sections points to the operation of forces of metamorphism, which have to this degree changed the original character of such a hard resistant rock.

Below are given the results of a chemical analysis, which, taken together with the microscopical evidence, determine the rock somewhat certainly as a rhyolite. The porphyritic tendency hardly seems to have gone far enough to admit of the rock being called a porphyry, although there are plainly two generations of mineralogical growth.

	I.	II.	III.	IV.	V.	VI.
SiO_2	74·08	72·24	75·20	73·91	74·66	76·06
Al_2O_3	11·10	13·62	12·96	15·29	11·49	12·37
Fe_2O_3	1·42	......	0·37	.....	2·02	2·05
FeO	0·61	3·05	0·27	0·89	. .	...
MnO	......	0·13	....	...	0·08	....
CaO	0·49	0·95	0·29	0·77	0·44	...
MgO	0·25	0·66	0·12	......	0·10	0·51
Na_2O	4·15	2·95	2·02	3·62	1·69	1·13
K_2O	7·42	5·24	8·38	4·79	8·68	6·99
Loss on ignition	0·25	1·05	0·58	1·19	0·74	1·21
Total	99·77	99·91	100·19	100·46	99·90	100·32

I. Rhyolite, Dundonald Township, Northern Ontario.

II. Quarzporphyr mikrogranitisch, Mühlberg bei Schwärtz unfern Halle, Rosenbusch, Elemente der Gesteinslehre, p. 245.

III. Rhyolite, Silver Cliff, Colo., Kemp, Handbook of Rocks, p. 28.

IV. Rhyolite, Pinto Peak, Eureka, Nev., Kemp, Ibid., p. 28.

V. Quarzporphyr mikrofelsitisch Platte bei Gross-Umstadt, Rosenbusch, Elemente der Gesteinslehre, p. 245.

VI. Quarzporphyr mikrofelsitisch, Grosserknollen bei Lauterberg. Rosenbusch, Ibid., p. 245.

The analysis of the Dundonald rock compares very favourably with the others given in the table in the case of all the important constituents.

(c) *Diabase.*—Five exposures of this rock occur in the portion of the township under study here. It occurs in boss-like masses not rising more than about twenty-five feet above ground. They are not by any means dyke-like projections. In the hand specimen, or on a polished surface, the typical diabase structure is plainly to be seen. The texture is very coarse-grained, and the constituent minerals are often as much as half an inch in diameter. Lath-shaped crystals of feldspar penetrate into the grains of the dark minerals, giving the rock the well-known ophitic structure. Hand specimens are easily attracted by a strong electro-magnet.

Under the microscope, thin sections resemble closely those of other diabases in the north country. The grain, however, is much coarser in the former, but this may be due to the comparatively large size and consequent slow cooling of the masses. The chief constituent minerals are four in number: (1) Feldspar.—Large lath-shaped crystals of feldspar are abundant. Twinning lamellæ are noticed but they are quite broad and often one band extends completely across the crystal fragment. On account of alteration which has rendered the mineral a dull gray, and made extinction quite imperfect, it was found difficult to accurately determine extinction angles. Some pieces, however, gave extinction angles measured on sections nearly at right angles to the albite twinning lamellæ, of 20° to 25°. This is sufficient to place the mineral very close to Labradorite in the triclinic series. (2) Augite; occurs abundantly in colourless to very pale brown grains, sometimes showing crystal outline. The prismatic cleavage is marked, and is emphasized by iron oxide stain which resulted from the gradual decomposition of the mineral, and collected along cleavage lines, and fractures. The grains are usually large, and often occupy nearly the whole field of the microscope. (3) Biotite; occurs in flakes and shreds, the latter showing marked pleochroism, green to brown. The flakes are often large, and of a green colour; they are always mottled with blotches of brownish iron oxide, the result of decomposition of the mica. Alteration to chlorite has in most cases progressed, and many of the characteristics of the biotite are often masked. From a quantitative point of view, this mineral is much less important than either of the first two. (4) Magnetite; occurs in grains, seldom with regular crystal outline, and is quite an important accessory mineral in the rock. In nearly all respects the sections closely resemble those of other diabases from northern Ontario, and the degree of alteration is about the same in both.

IV. Nature of the Deposit.

In "Economic Geology," Volume V, No. 4, 1910, a short account of the "Alexo Nickel Deposit" was given by Dr. A. P. Coleman. He describes in a general way thin sections of the serpentine, and has the following to say of the pyrrhotite-serpentine rock: "It proves exceedingly interesting. There is every gradation from ore with a few well-formed crystals of olivine (now transformed to serpentine) floating in it, to serpentine with a small amount of ore replacing the turbid matrix between the crystals . . . . . . The general appearance of the ore and the arrangement of the ore-body suggest strongly the marginal deposits of the Sudbury Nickel range. There is every reason to suppose that the Alexo deposit has accumulated in the lower part of a bay-like curve of the country rock while the magma was still molten, as has been proved to be the case, with the Sudbury marginal mines." Dr. Coleman, therefore, seems to be quite convinced that the ore-deposit is of the magmatic segregation type. The chief characteristics of the occurrence are: (1) the ore is nickeliferous pyrrhotite, marcasite, chalcopyrite; (2) it is collected along one side of a body of a basic rock, or at its contact with another rock; and (3) the rock with which the ore is associated is an altered member of the peridotite group, and one of the most basic of known rocks.

Keeping these three points clearly in view, it may be profitable to review rapidly the chief characteristics of a few other nickel areas.

(a) *The Sudbury Nickel Area.*—The nickel-bearing eruptive occupies a synclinal basin in a country of granite gneiss. The thickness of the eruptive sheet is somewhere in the neighborhood of 1.25 miles. (1) A series of Huronian sediments lies on top of the sheet. The latter, before crystallization, underwent an extensive process of differentiation, and all stages of basicity are observed from a granite at the upper margin to a norite against the outer edge. The ore, which consists of nickeliferous pyrrhotite, chalcopyrite and pentlandite is found along and near the basic edge and associated with the norite phase of the intrusion. Norite is without doubt a basic rock, consisting of plagioclase and rhombic pyroxene, but by no means as basic as a peridotite. Dr. Coleman* (1), as well as Dr. Barlow* (2), Prof. Vogt* (3), Dr. Adams* (4) and others, are convinced that the deposit is one of the segregation type while Posepny* (5), Dickson* (6), and others

*(1) Sudbury Nickel Region, by A. P. Coleman, p. 11.
*(2) Summary Rep. of the Director, Geol. Surv. of Canada, 1901.
*(3) Zeitschrift für Prakt. Geol., 1893, April, p. 125.
*(4) Canadian Mining Review, Jan. 1894, p. 8.
*(5) Trans. A. I. M. E., XXIII, p. 330.
*(6) A. I. M. E., Vol. XXXIV, p. 25.

advocate the theory of aqueous depositions of the ores. The chief points of this occurrence are: (1) the ore is a sulphide carrying nickel; (2) it is collected along and near the margin of a basic intrusion; and (3) the associated rock is one of the gabbro series, norite.

(b) *Gap Mine, Lancaster County,** (1)—"From the mine to Baltimore the region is marked by a great development of basic igneous intrusions . . . . . In all the exposures the original pyroxenic rock shows marked alterations, secondary hornblende, (or even in extreme cases, serpentine) being the result. Chromite deposits have been widely met, doubtless a result of the change to serpentine. The nickel-mine is associated with one of the smallest of these exposures of basic rock, which is also the most remote north-western outlier. . . . . The ore consisted of pyrrhotite and chalcopyrite in largest amount; but pyrite was not lacking. . . . . The pyrrhotite is irregularly mingled with the hornblende, appearing in large and small masses, Chalcopyrite is intimately associated with it." Prof. Kemp regards the deposit as the result of magmatic differentiation, but admits that concentration by aqueous agencies was later active as evidenced by the presence of crusts of millerite, and stringers of quartz and vivianite.

(c) *New Caledonia**(2).—Ancient schists and mesozoic sediments are penetrated by a peridotite, consisting of olivine and, enstatite, now more or less transformed into serpentine. Deposits of nickel, cobalt and chromium are associated with the serpentine. The original peridotite is no doubt the source of the ore, and analyses show that the fresh rock contains small percentages of nickel and cobalt. The ores are all hydrated silicates in which nickel has replaced magnesium to a greater or less extent. The green minerals (nickel silicates) occur as small veins in the serpentine, as a scaly covering of fragments of the rock, or as concretionary masses. The deposits have resulted from the superficial weathering of the rock, accompanied by a concentration of the nickel as silicate by surface waters, the nickel being precipitated more readily than the magnesium. The chief points here of value for the sake of comparison are: (1) The ore is a silicate, not a sulphide; (2) it is associated with one of the most basic of igneous

*(1) J. F. Kemp, A. I. M. E., XXIV, p. 620.
*(2) Account taken from "Sudbury Nickel Field"—Coleman, pp. 147-149.

rocks, a serpentine, as at the Alexo Mine; (3) it does not occur merely along contacts, but as stringers, veinlets, coverings, masses all through the serpentine.

(d) A few other occurrences may be mentioned briefly. E. S. Bastin publishes a very interesting account of a pyrrhotite-peridotite rock from Maine, U.S.A.*(1). Although no deposit of economic value occurs there, the rock itself appears on first sight very similar to the pyrrhotite-serpentine rock at the Alexo Mine. A few quotations will be to the point:—"It is medium-grained, holocrystalline, and equigranular, and is composed of a yellowish-gray, metallic-looking mineral, which proves to be pyrrhotite scattered in very irregular masses through a ground-mass which for the most part appears structureless and is dark green to nearly black in colour. . . . . Most of the nearly black matrix between the sulphide masses exhibits no trace of cleavage and is shown under the microscope to be olivine, its dark colour being due to the abundance of minute magnetite inclusions which it contains. . . . Serpentine and chlorite, which have resulted from olivine and hornblende decomposition, are confined largely to certain layers which are thread-like in form as seen in cross-section on a polished surface. . . . . The olivine occurs in rounded grains ranging from 1 or 2 mm. to 8 mm. in length, the majority being between 3 mm. and 4 mm. Most of the grains are entirely fresh except for a narrow alteration zone of fibrous serpentine about their borders. Certain narrow bands traversing the rock in a manner already described are characterized, however, by much more extensive alteration, and in these areas the olivine grains may be partly or wholly serpentinized, the alteration having, as is usual, been most extensive along the irregular cracks and about the peripheries of the grains. . . . . The pyrrhotite is normally completely allotriomorphic with respect to olivine grains. . . .
The allotriomorphic relation of nearly all the pyrrhotite to unaltered grains of the original mineral olivine is considered to be conclusive evidence that practically all the pyrrhotite is an original crystallization from the magma, and is essentially contemporaneous with the other principal constituents of the rock . . . . . The rock exhibits an unusual concentration of metallic sulphides common

*(1) Pyrrhotite-Peridotite from Knox County, Me.,—A Sulphide Ore of Igneous Origin—E. S. Bastin, Jour. of Geol., Vol. XVI, p. 124.

in many ore-deposits, and from a theoretical standpoint at least may be regarded as an example of ore formed by original crystallization from the molten magma." The following are the chief points of difference between this occurrence and that in Dundonald Township: (1) In Knox County, Me., there is no ore free altogether from admixture with rock; (2) the rock itself is fresh; (3) olivine occurs in irregular grains, not crystals; (4) the rock contains feldspar and hornblende.

Rossland, B.C.—Althought this is a gold camp, the structure of the deposit is worthy of notice in this connection. The country rock is an augite porphyrite, which has been fractured and cut by dykes. The veins occupy shear zone fissures consisting of a series of parallel platings of the rock produced by shearing under high compression. The ore consists of country rock more or less replaced or impregnated by pyrrhotite, accompanied in places by small proportions of chalcopyrite, pyrite, arseno-pyrite and quartz. The pyrrhotite carries but little gold. The chalcopyrite is the principal carrier. The manner in which this mineral (together with pyrite and arsenopyrite) occurs within the interstices of the pyrrhotite, and the fact that continuous masses of pyrrhotite ore are impregnated in some places and barren in others, proves the later deposition of these valuable minerals. In various places, the pyrrhotite seems to be accompanied by a little nickel and cobalt, specimen analyses ranging from 0·13 to 0·65 per cent nickel, and from a trace to 0·59 per cent cobalt.*(1). Mr. R. W. Brock*(2) considers the deposit to be the result of aqueous deposition, but says that the development of contact minerals observed suggests a high temperature for the mineralizing solutions. In many respects the origin of the ore-body presents a parallel case with that of the Alexo Mine. Polished specimens of the basic country rock in process of replacement by filaments and net-work of pyrrhotite offers a striking resemblance to polished specimens from Dundonald. (Plate V, No. 5.)

(c) *The Case at the Alexo Mine.*—The weight of evidence so far deduced respecitng nickeliferous sulphide deposits, whose origin has been a matter of controversy, has been decidedly in

*(1) Account taken from "The Ore-Deposits of Rossland, British Col.," by E. B. Kirby—Jour. Can. Min. Inst., Vol. VII.

*(2) "Rossland B. C. Mining Dist." By R. W. Brock, Geol. Surv. of Can., No. 939.

favour of the theory of magmatic segregation. Segregationists, however, have generally agreed that aqueous agencies have been active in the final concentrations of the ore. Dr. C. W. Dickson made a rather exhaustive study*(1) of certain aspects of the Sudbury deposits, proving to his own satisfaction an aqueous origin for the sulphide ores. His opponents, however, argue that he only made an examination of certain features of the whole area, and that in these, secondary concentration by solutions had largely obliterated the ear-marks of the original differentiation process. Conditions at the Alexo Mine hardly seem capable of a similar interpretation. Many of the noticeable features of this deposit seem at first to bear a marked resemblance to some of the aspects of one or other of the deposits above described. The pyrrhotite in the first place is collected around the margin of the serpentine; it is succeeded after a short distance by a "mixture" of pyrrhotite and serpentine, which in many respects resembles the pyrrhotite-peridotite rock of Knox County, Maine. A somewhat detailed examination of the "mixture" from the Alexo Mine, in the way of microscopical investigation of several thin sections, together with a reproduction of some of the interesting features as micro-photographs and photographs of polished surfaces, lends considerable support to the belief that this ore-deposit is not a case of differentiation from an intrusive magma. The results of the examination are given herewith:—

(1) There is a gradual transition in the amount of ore present, from solid ore extending for four or five feet out from the wall, to pure serpentine at a distance of about ten or twelve feet from the wall. The contact with the rhyolite is exceedingly sharp, and a contact zone of only a few inches is noted.

(2) Idiomorphic crystals of olivine, in nearly all cases completely altered to serpentine, appear to be floating in a matrix of pyrrhotite (Plate II, Nos. 2–5). The crystal outlines are sharp, and in many cases perfect, showing no evidences of rounded angles or edges as might be expected if they had lived for a time in a previously differentiated molten mass of pyrrhotite. If the pyrrhotite had separated out while the magma was still molten, and gravitated towards the periphery, how would the olivine crystals, which must have crystallized at least a little later, and

*(1) Trans. A. I. M. E., Vol. XXXIV, pp. 25-65.

which have a much less specific gravity, than the sulphide, have come to sink so deeply into the body of the latter?

(3) The ore itself even in specimens taken from near the periphery shows black spots scattered abundantly through it, and which were originally crystals of olivine, now transformed completely to magnetite. This feature is plainly noticeable on polished surfaces of the ore. Thin sections of the rock made from specimens which have become nearly solid ore, also show this phenomenon admirably. Plate II, No. 6, is an example of a few olivine crystals which have been changed to magnetite and now lie in a matrix of pyrrhotite. Examples like this seem to indicate pretty strongly that what is now ore was at one time a peridotite of the same nature as the rock about twelve feet from the contact.

(4) The pyrrhotite is seen to be eating its way through the matrix of the serpentine, extending from one place to another in bunches of dust-like particles, and eventually occupying all the space in the interstices of the crystals. (Plate III, Nos. 1-4.)

(5) In other cases, veinlike stringers of pyrrhotite appear to be worming their way through the matrix, replacing it, and forming a network of ore. (Plate III, Nos. 5, 6, and Plate IV, No. 1).

(6) Often, the ore extends from the spaces between the crystals into fractures and cracks in the latter (Plate IV, No. 2 and Plate III, No. 3). It is difficult to conceive how this could be explained, if the ore were deposited before the alteration of the rock.

(7) Frequent examples may be found of the ore replacing part or all of an olivine crystal, and tending to produce a pseudomorph. (Plate II, No. 5, Plate III, Nos. 3 and 5.)

(8) Sometimes, the magnetite pseudomorphs, which have resulted from the alteration of the olivine, have become partially or wholly replaced by pyrrhotite.

(9) The serpentine rock is traversed by veinlets of asbestos, These are numerous, as can be seen by examining the dumps at the mine. The original peridotite during its alteration was under great expansional stress, owing to absorption of water to form the hydrated silicates. Evidences of this stress are very common in the way of faults and small fractures with slickensided surfaces. These fractures, which are usually only of a couple of millimetres in thickness, are now the asbestos veins, mentioned above.

Examples of these may be seen in Plate IV, Nos. 4-6, which are from photographs of polished surfaces. It is important to note that in none of the cases examined was an asbestos vein seen to cut through particles of pyrrhotite. On the other hand, in nearly every case, small stringers or veinlets of pyrrhotite run along the sides of the veins and send slender offshoots in between the fibres of the asbestos (Plate IV, Nos. 4-6). This seems good proof of the fact that the ore was an infiltration of later date than the formation of the veins. It is also noteworthy that the rock is much richer in ore in the proximity of these asbestos veins whose walls seem to have afforded channels for the depositing solutions.

(10) Ore is seen to be replacing the secondary pyroxenic material of the contact zone of the rhyolite, but has apparently no effect on the acidic constituents of the latter.

(11) The sharp definition of the wall, in the direction of the rhyolite, is due to the absence of much basic material in this rock, to be replaced by the solutions. Abundance of this in the direction of the serpentine accounts for the position of the ore and the presence here of only a "commercial" wall.

(12) If, as is believed, the rhyolite is an extrusion through the serpentine, the formation of the wall against which the ore rests is of later date than the solidification of the basic rock. The sulphides could not have been deposited, therefore, until after the appearance of the rhyolite.

The above evidence seems to point without doubt to the origin of the ore-body by deposition from percolating sulphide waters. The genesis of the nickel content of the ore may be difficult to establish, but the analysis of the serpentine shows the presence of small amounts of NiO (0·59%). Whether the nickel was leached from this rock, or brought in solution from other parts is not the purpose of this paper to investigate.

V. THE ORE.

The ore itself, in respect of the relationships existing between the different constituent minerals, makes a very interesting subject of study. The percentage of nickel is high, and an average sample assayed 7·08%. This immediately suggested the presence of pentlandite. Resort was made to metallography, and several specimens of the ore polished*(1), and then etched by immersion for one-half minute in a boiling solution of HCL (1:1). Photographs of some of the results obtained are given on Plate V (Figs. 1-4). Chalcopyrite and magnetite are distinguished by their colour on the polished surface, the former being a rich brass-yellow, and the latter a dull steel-gray. Only a very little chalcopyrite was detected, and a chemical analysis of some specimens gave no copper. Magnetite is present as an original crystallization, and shows cubic outlines. Etching brings it out strongly in relief.

The most important information gathered from the etching is with regard to the large amount of pentlandite seen in some specimens. The composition of this mineral as given by Dana*(2) is: Sulphur, 36·0; iron, 42·0; nickel, 22·0. This no doubt accounts for the high percentage of nickel found in the Alexo ore. The almost unetched, delicately pitted surface, and the light bronze colour of this mineral serve to distinguish it clearly from the severely attacked, irregularly pitted pyrrhotite from which the former stands out in marked relief. Under the microscope, the pyrrhotite is seen as fairly large grains between and around which occurs the pentlandite. This is seen chiefly in the form of stringers and vein-like masses (Plate V, No. 3), which often continue in the same direction for a distance of half an inch to an inch. More often these veins are shorter and jog irregularly here and there. They even penetrate the grains of pyrrhotite, evidently along lines of weakness. From the examination of such facts as these it is necessary to conclude that the pentlandite was deposited at a later stage than the pyrrhotite.

Magnetite, distinguished by its steel grey colour, both on the polished surface, and on the etched surface (being unattacked it stands in relief with the pentlandite) seems to have been about the earliest formed constituent of the ore. It is found usually as octahedral sections (Plate V, No. 4) or as almost perfect octahedrons, the surrounding pyrrhotite in which they were embedded being dissolved away. Traces of gridiron structure may be noticed under the microscope.

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*(1) Wm. Campbell: "The Microscopic Examination of Opaque Minerals," Econ. Geol., Vol. I, No. 8, 1906, p. 751.

*(2) Dana "Text-book of Mineralogy," p. 293.

Chalcopyrite, as mentioned above, is only present in small amount. However, on the etched surfaces under the microscope small lenticular masses of it can be seen intimately associated with the pentlandite, and like the latter, remaining unetched. Also, it occurs in capillary filaments usually found along the sides of the small fractures between the grains of the pyrrhotite. It is very closely associated with the pentlandite, and it is difficult to say which of the two is the older.

These results are in close accordance with those obtained by W. Campbell and C. W. Knight*(1) in their examination of specimens from Sudbury, Ont., St. Stephen, N.B., the Gap Mine, Penn., two Norwegian localities; and Sohland, Germany. The order of deposition worked out by them is: (1) Magnetite; (2) silicates; (3) pyrrhotite; (4) pentlandite; (5) chalcopyrite. The order of deposition at the Alexo mine, as indicated in the foregoing description is: (1) Magnetite; (2) pyrrhotite; (3) pentlandite and chalcopyrite. It is possible that the chalcopyrite is here also younger than the pentlandite, but the examination of the surfaces etched did not justify the writer in drawing that conclusion.

The study of the ore specimens therefore tends to further substantiate the theory of replacement for the origin of the deposit. It is difficult to conceive of the sulphides as differentiations from a molten magma, when they were as a matter of fact deposited one after another, the younger ones occurring as vein-like masses in the older.

VI. CONCLUSION.

From the manner in which the ore occurs as a sheet-like mass against the wall of rhyolite, and because of the short distance in which the change takes place from pure ore to pure serpentine, it is evident that the deposit was formed through the agency of aqueous, mineral-laden solutions. Any doubts on this point are removed by the examination of thin sections, which show filaments of ore eating their way here and there, and gradually replacing the original rock constituents, particualrly the pyroxene and mica. The source of the mineral-bearing solutions and that of their

*(1) Campbell and Knight: "On the Microstructure of Nickeliferous Pyrrhotites." Econ. Geol., Vol. II, No. 4, 1907, p. 350.

mineral content must be largely a matter of speculation, but it is a fact worthy of consideration that in the immediate vicinity, there are five exposures of a diabase rock, probably of post-middle Huronian age. In Northern Ontario, the diabase almost without exception carries traces of nickel, as nicolite or cloanthite; and here at least is a possible origin for some of the nickel content.

It may be mentioned that the serpentine is well seamed with small asbestos veins of moderately good fibre; and also that it contains a high percentage of chromic oxide (1·65%). In both of these respects, the rock simulates other occurrences of serpentine in Northern Ontario.*

Special acknowledgments are due, amongst others, to Dr. W. G. Miller, Toronto, who kindly afforded the writer the time and means for the field examination in September, 1910, and to Mr. C. W. Knight, Toronto, for information with regard to etching, and for the use of thin sections of diabase from Northern Ontario, for purposes of examination and comparison.

* Bureau of Mines Report, Lake Abitibi Area, M. B. Baker, 1909, p. 273.

EXPLANATION OF PLATES.

Plate II (Nos. 1-6 are thin sections).

No. 1.—Serpentine free of ore, showing crystals of chromite and outlines of decomposed crystals of olivine. Ordinary light (x 20 diams.).

No. 2.—Pyrrhotite-serpentine, showing ore replacing the matrix between idiomorphic crystals of olivine (now serpentine. Ordinary light (x 20 diams.).

No. 3.—Same, showing olivine crystals (x 20 diams.).

No. 4.—Same (x 20 diams.).

No. 5.—Same, showing pyrrhotite, gradually replacing the altered olivine (x 20 diams.).

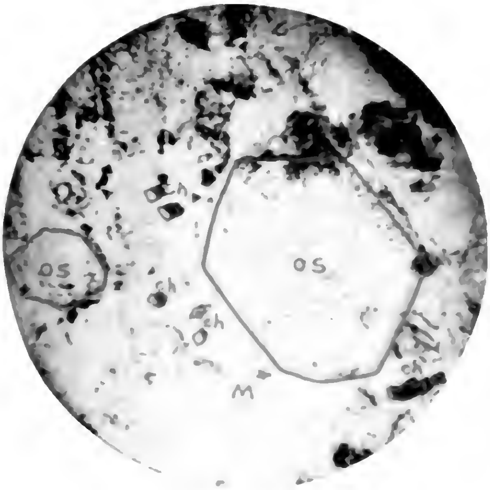
No. 6.—Same, showing olivine crystals, completely transformed to magnetite: Section represents nearly solid ore (x 20 diams.).

Plate III (Nos. 1-6 are thin sections) (x 20 diams.).

Nos. 1 2.—Same, showing ore in dust-like particles (black) scattered through the white matrix.

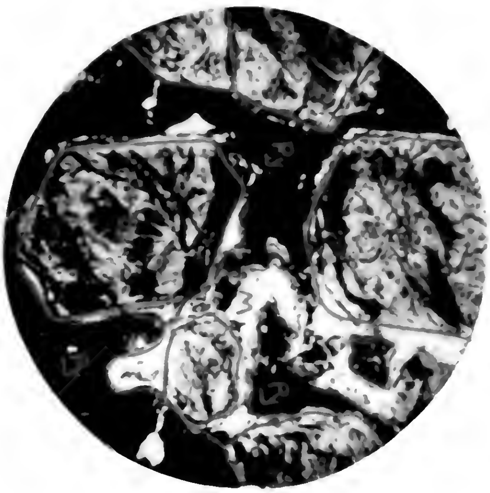
No. 3.—Same, showing crystals of olivine, with ore eating its way through fractures to centre of crystal.

PLATE II



No. 1

No. 2



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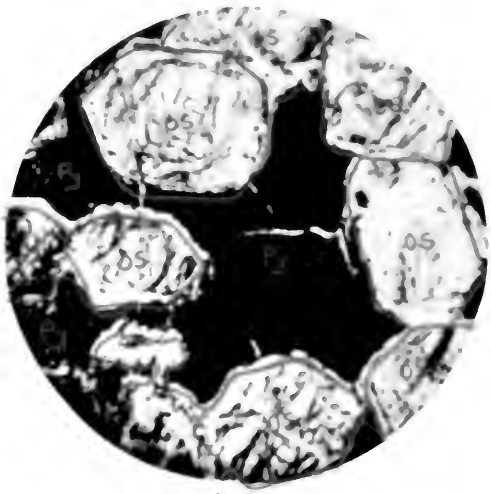
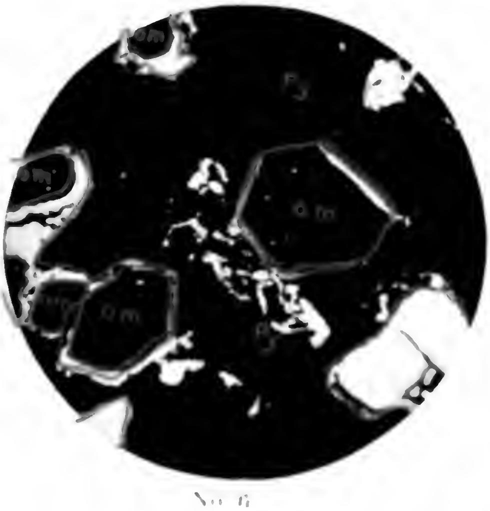


No. 4



No. 6

No. 5

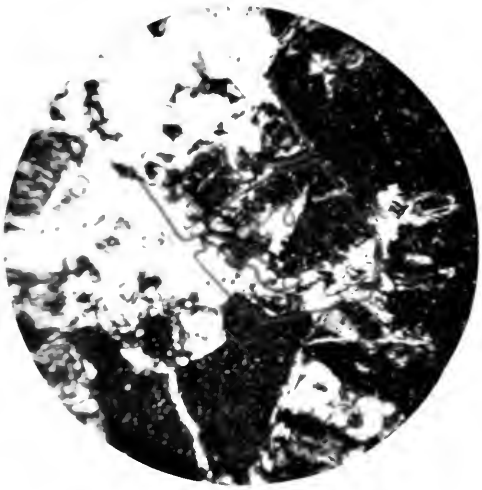
LEGEND

Os = Olivine crystal, altered to serpentine
Om = Olivine crystal, altered to magnetite
Py = Pyrrhotite and Pentlandite
ch = Octahedral crystals of chromite
M = Unreplaced matrix (chlorite, biotite, etc.) serpentinized

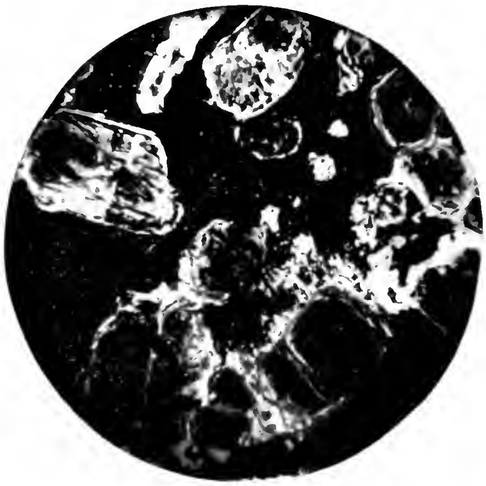
PLATE III

No. 1

No. 2



No. 3



No. 4

No. 6

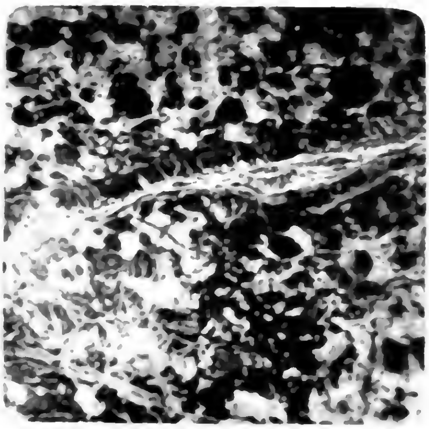
LEGEND

[illegible] crystal, altered to serpentine
[illegible] crystal, altered to magnetite
[illegible] and Pentlandite)
[illegible] matrix (diallage, biotite, etc.) serpentinized
[illegible]

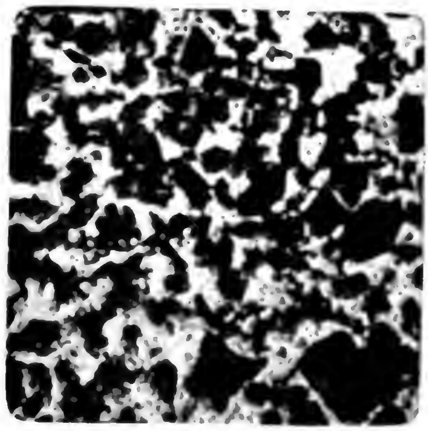
PLATE IV

No. 1

[illegible]



No. 4



[illegible]

No. 6

[illegible]

[illegible]

OS — [illegible]
Ps — [illegible]
Psa — [illegible]
M — Matrix
S — [illegible]
As — Asbestos Vein
Py — [illegible]

Plate V

No. 1

No. 2

No. 3

No. 4

No. 5

Legend.

Po = Pyrrhotite grains
Pe = Pentlandite, in veinlike masses
Mg = Magnetite crystal

No. 4.—Same, showing dust-like particles of ore (black).

No. 6.—Same, showing vein-like masses of ore; also partial replacement of olivine crystals by pyrrhotite and pentlandite.

Plate IV (Nos. 1-2 are thin sections; Nos. 3-6 are polished surfaces).

No. 1.—Same, showing ore (black) in dust and veins (x 20 diams.).
No. 2.—Same, showing ore occupying a fracture in an olivine crystal (x 20 diams.).
No. 3.—Polished surface, showing net-work of ore (gray) eating its way around crystals of olivine (black) (x 7 diams.).
No. 4.—Same, showing vein of asbestos, with ore (gray) collected in stringers along its side, and in between the fibres (x 3 diams.).
No. 5.—Same enlarged, showing well the vein-like nature of the ore (x 10 diams.)
No. 6.—Same (x 10 diams.)

Plate V.

No. 1.—Etched surface of ore, showing pentlandite in vein-like masses.
No. 2.—Etched surface of ore, showing pentlandite in vein-like masses. Pyrrhotite is out of focus, being etched.
No. 3.—Same; black stringers is a fracture in the ore.
No. 4.—Same shows pyrrhotite (etched), and crystals of magnetite unetched and in relief.
No. 5.—Polished surface of Rossland rock, showing replacement by pyrrhotite.

THE CHARACTER AND POSSIBLE ORIGIN OF THE GREEN DOLOMITES OF NEW ONTARIO.*

By N. B. DAVIS, School of Mining, Kingston, Ont.

In intimate association with the gold veins of the areas about Larder, Night Hawk, Porcupine, and the Abitibi lakes, in Ontario, and the north end of Opasatica lake, in Quebec, occur bands of a bright green, rusty weathering, dolomite rock. It has been described by various writers as "serpentinized dolomite,[1] "rusty weathering dolomite,"[2] "ferruginous dolomite or ankerite,"[3] "silicified dolomite,"[4] etc., of Keewatin age.

During the summer of 1909 the writer acted as assistant to Mr. M. E Wilson, of the Geological Survey of Canada, in a survey of the Larder Lake district. Specimens of the bright green carbonate, from the various bands in the vicinity, were gathered with the object of investigating the mineral that gave the bright green colour to the rock. The results of this examination tended to disprove the sedimentary theory as to the origin of the bands, and hence the work was carried on to cover the origin.

SOURCE OF MATERIAL.

Besides the material gathered by the writer in the Larder Lake area, Prof. M. B. Baker contributed a specimen from Abitibi lake, and Mr. W. L. Uglow one from Night Hawk lake. From a recent description of the Porcupine area, it appears that the green dolomite of that district is similar to that of Larder lake. The occurrence at the head of Opasatica lake is the same as that at

* Student members' competition, 1911, awarded second prize.

[1] [2] Prof. Brock, Bureau of Mines, 1907, p.

[3] Mr. M. E. Wilson, Summary, G.S.C., 1909, p.

[4] Mr. M. B. Baker, Bureau of Mines, 1909, p.

Larder. In all probability it is a continuation of the band exposed at the "Reddick Mine" on the north-east arm of Larder lake, the Keewatin being covered by Huronian sediments.

Dolomites in which the green mineral is developed, have been reported from the Keewatin of Bolton and Sutton Townships, in in Quebec,[1] from Aird island, at the mouth of the Spanish river,[2] Lake Huron, and from Matawachan Township, Renfrew county, Ontario.[3] The same green mineral is also found in the gangue of a nickeliferous pyrrhotite from Hyman township, Algoma district.[4]

GEOGRAPHY AND GENERAL GEOLOGY.

The accompanying map will show the general distribution of the green dolomite in New Ontario and north-western Quebec. Ontario has been prospected more thoroughly than Quebec, and hence four areas in which the green dolomite occurs, are known in Ontario, and one in Quebec.

Accounts of the general geology of the occurrence of the green dolomite will be found in the reports of the Geological Survey and the Ontario Bureau of Mines.

III.—ABITIBI LAKES.

The deposits of gold in the rocks exposed on the shores and islands of the Abitibi lakes, visited by Dr. Miller in 1906, and by Prof. M. B. Baker in 1909, are different in some respects from those described by Prof. Brock and Mr. Cole on Larder and Night Hawk lakes respectively. The chief resemblance is that the same green mineral is found in some of the deposits at Abitibi as that in the deposits of the other two lakes. The green mineral occurs in thin bands of a silicified dolomite. The bands are much sheared, and the green mineral is best developed along the schistosity. See Fig. 2.

A report on the Porcupine district, by Mr. A. G. Burrows, has just been published by the Ontario Bureau of Mines.[5]

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[1] Report G.S.C., Vol. XVI, p. 231 A.

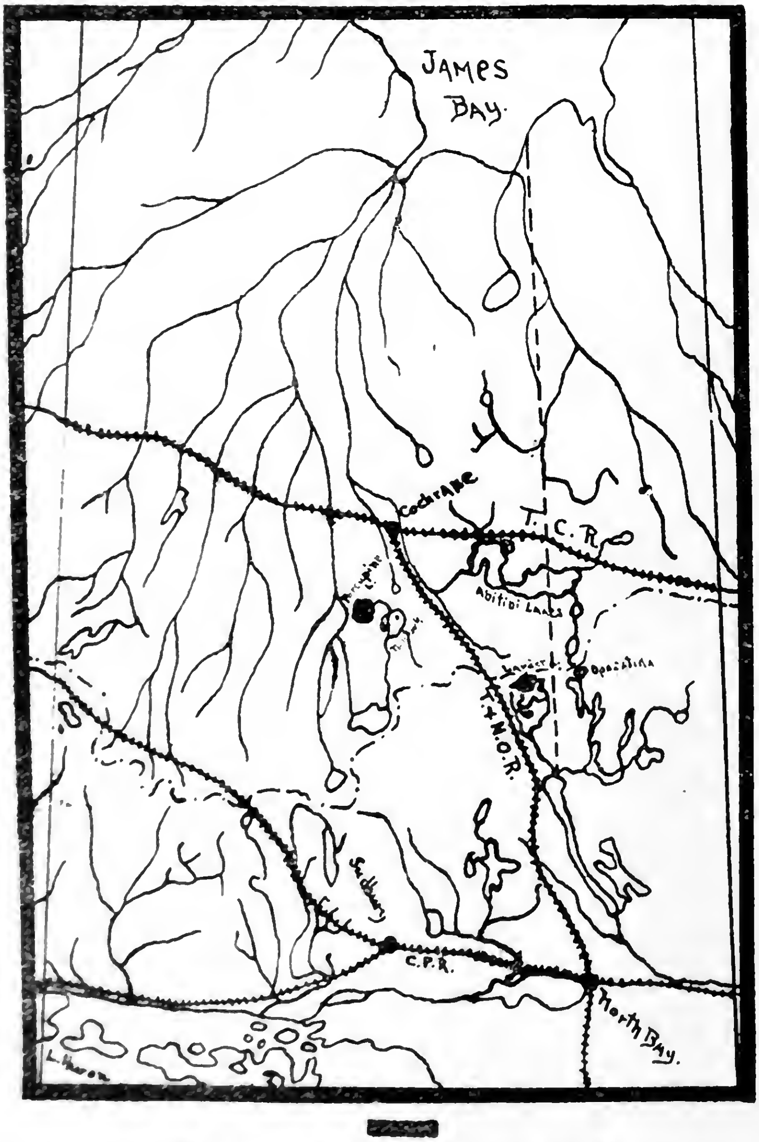
[2] Am. Jr. Sc., Vol. 33, p. 284.

[3] Report G.S.C., Vol. V.

[4] Report G.S.C., Vol. VI, p. 13 R.

[5] Twentieth Report Ont. Bureau of Mines, Part II, 1911

In the Feb. 15th, 1911, issue of the Canadian Mining Journal Mr. John Stansfield, of McGill University, describes sections cut from typical rock specimens from the Porcupine district. The sections described are much like those examined by the author from Larder lake, but he makes no mention of chrome mica.



GREEN DOLOMITE AREAS.

PETROGRAPHY.

No. 1.—Typical section of the green dolomite from the Reddick Mine, north-east arm, Larder lake. The carbonate is a

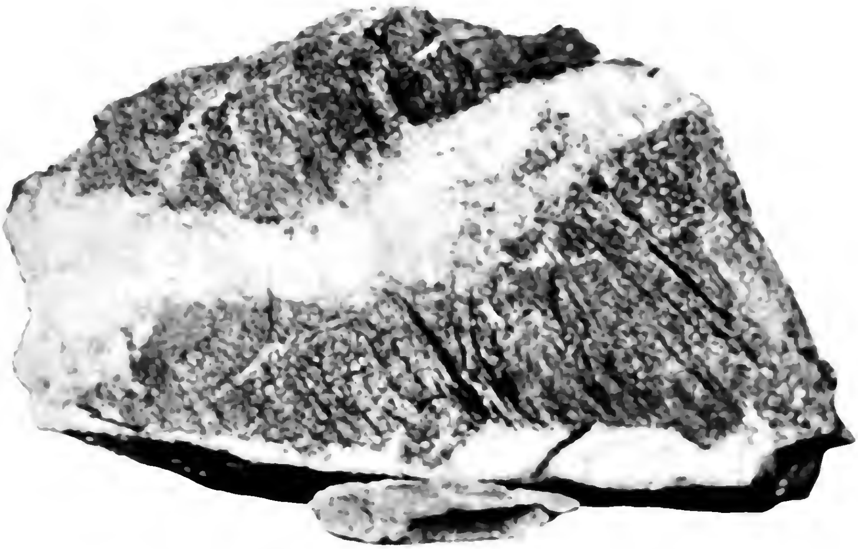


Fig. 1

mixture of calcite and dolomite showing no outward crystal form, but good rhombohedral cleavage, and wide twinning bands. The grains, varying in size, show dissolution along the schistosity and the spaces, thus formed, are filled with secondary quartz. The quartz, in places, is full of little cleavage rhombs of carbonate and long and short needles of a greenish to brown mineral, probably tourmaline. In general, the mica is in shreds developed along the lines of schistosity; the individual shreds are not large enough to be examined in detail. In places it is associated with yellow specks of limonite. Pyrite, also is present in small amount.

No. II.—Section from a specimen collected in the open cut on the Harris-Maxwell claim, Larder lake. Free quartz makes up about 30% of the mass. The rest of the rock is made up of carbonate, probably dolomite, some basic feldspar, much decomposed, and plates and shreds of greenish mica full of needle-like inclusions. Brown flakes of limonite are present along the schistosity. Some pyrite is also present. A grain of chromite was also observed surrounded by a collar of green mica (?). See Fig. VI.

No. III.—Section from a specimen from the shore of Night Hawk lake. The section is much the same as No. 1 in composition. The carbonate does not show the same amount of shearing nor does it show as abundant twinning, indicating a composition more like dolomite or magnesite. The mica occurs in very fine shreds throughout the whole section. The quartz is mostly secondary in character and full of inclusions of the carbonate, shreds of mica and short needles of the tourmaline like mineral.

THE MICA.

Microscopic.—The mica in the rock from the Harris-Maxwell mine is of two colours, white and green. The green variety is so mixed with white, in places, that it is hard to separate them. However, the white variety is not well developed. One small crystal was found where the green mica was an isomorphous growth on a core of the white. See Fig. VII. Fig. VIII will show the distortion the mica has undergone by the shearing of the rock. Some flakes that have escaped distortion show a distinct hexagonal outline.

Microscopic.—Under the microscope the mineral has a slight greenish tinge in thin section. It is not noticeably pleochroic, but is full of minute needle-like inclusions, arranged in radiating wheel-like structures, like the arms of a percussion figure. The analysis of the mica indicates that they are probably titaniferous tourmaline. The mica extinguishes parallel to the cross hairs and answers the other properties of muscovite mica. Figures II and III show the inclusions and Fig. V, a mica shred.

CHEMICAL ANALYSES.

Analyses of the samples from Larder, Night Hawk, and Abitibi lakes resulted as follows:—

	A	B	C	D
SiO_2	30.63	36.90	44.06	
TiO_2	0.10	0.19		
Al_2O_3	1.66	7.47	20.00	
Cr_2O_3	0.10	0.26		0.20
Fe_2O_3	2.78	6.56		
FeO	......	3.12	......	
MgO	12.98	18.47	7.45	
CaO	26.02	8.02	7.48	
MnO	0.09	Trace	0.07	
Na_2O	0.03	0.02	......	
K_2O	0.20	0.16	......	
CO_2	24.31	17.58	15.10	
H_2O	0.14	1.20	0.24	
S	0.41	0.11	NiO=0.06	
Boron	Trace	Strong Test		
Total	99.45	100.06		

A. Analysis of specimen from Reddick mine, Larder lake.
B. " " " Night Hawk lake.
C. " " " Harris-Maxwell mine, Larder lake.
D. Chromium sesquioxide percentage in the sample from Abitibi.

In the chemical work, the procedure given by Hillebrand in U.S.G.S. Bull. No. 422 was followed. Time did not permit a complete analysis of the last two named samples; only those constituents, therefore, with a bearing on the origin were determined.

An analysis of the green mineral resulted as follows:—

SiO_2 . .	43.34
TiO_2	1.06
Al_2O_3	24.41
Cr_2O_3 . .	1.53
Fe_2O_3 } FeO }	0.40
MnO	
CaO	5.90
MgO	4.96
Li_2O	none
Na_2O	0.90
K_2O . .	4.35
H_2O . .	13.28
Boron . .	strong
Total	100.13

This analysis indicates, that the mineral is a chrome mica, high in moisture and lime. Evidently moisture has replaced some of the alkali and lime some of the alumina. Iron is nearly absent as in normal muscovite. The inclusions furnish some moisture, calcium, magnesium and titanium, and in all probability the boron.

For comparison, analyses of chrome mica similar to the above, are given, arranged in the order of the silica content. In general it will be noted, that with the decrease in percent of alumina and chromium sesquioxide, there is corresponding increase in the per cent. of lime.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	42.21	43.34	43.72	45.49	45.68	46.17	46.50	47.95	55.35
TiO_2	......	1.06	......	......	......	......	......	......	0.18
Al_2O_3	34.55	24.42	35.51	31.08	34.17	29.71	......	34.45	25.62
Cr_2O_3	2.03	1.53	1.26	3.09	0.84	3.51	0.90	3.95	0.18
Fe_2O_3	1.03	0.40	2.98	Tr.	2.35	2.03	37.20	1.08	0.63
FeO									0.92
MnO	Tr.	......	0.26	......	......	......	......	......	
CaO	0.47	5.90	4.46	0.51	0.27	......	......	0.59	0.07
MgO	3.13	4.96	1.36	3.36	3.84	2.28	0.80	0.71	3.25
Li_2O	......	......	......	......	Tr.	......	......	......	Tr.
Na_2O	0.12	0.90	0.39	0.90	2.23	......	1.30	0.37	0.12
K_2O	9.29	4.35	8.88	9.76	4.47	10.40	7.90	10.75	9.29
H_2O	4.52	13.28	3.68	5.85	4.64	5.42	4.70	......	4.52
Boron	......	Strong Test	......	......	......	......	.... F	=0.36	
Total	100.13	100.13	102.46	100.04	98.50	99.52	99.30	100.93	100.13

Analysis No. I —Chrome Mica from Maryland. U.S.G.S. Bull. 64.
" No. II —Chrome Mica from Larder lake, Ont. By the writer.
" No. III —Chrome Mica from Keewatin of Matawatchan township, Renfrew County, Ont. G.S.C., Vol. V, p. 21 R.
" No. IV —Chrome Mica from Aird Island, Lake Huron. Am. Jr. Sc., Vol. 33, 1887.
" No. V —Chrome Mica from Salm Chateau, Europe. Dana.
" No. VI —Chrome Mica from Sysersk, Europe. Dana.
" No. VII —Chrome Mica from Auro Preto, Europe. Dana.
" No. VIII —Chrome Mica from Tyrol, Europe. Dana.
" No. IX —Chrome Mica from Mariposa Co., California (Mother Lode). Ann. Report, U.S.G.S., pt. I, p. 678.

Mr. R. G. McConnell reports a chromiferous muscovite mica from several places in the Yukon.[1]

He also mentions its occurrence 300 miles to the north-west of the above locality, and again in a north-westerly direction in a white dolomite about a mile and a half above Hunker creek, on the Klondike river.

In nearly every case where the occurrence of chrome mica has been reported, the holding rock has been described as a dolomite or magnesite. Where it is not with dolomite or magnesite, it is in the gangue of nickeliferous pyrrhotite, as reported from Hyman township, Algoma.[2]

[1] Report of G.S.C., Vol. XI, p. 15 R.

[2] Report of G.S.C., Vol. VI, p. 27 R.

THE POSSIBLE ORIGINS.

Two possible origins for the green dolomite suggest themselves. The first is a sedimentary origin suggested by the writers of the reports quoted in the first part of this paper. The second is an igneous origin suggested by the writer.

(A) SEDIMENTARY ORIGIN.

As no fossil remains are found in these highly metamorphosed Pre-Cambrian dolomites, the only evidence we have to prove them of sedimentary origin is the apparent conformity of the bands with other bands thought to be of sedimentary origin. At times they are conformable with sheared graphitic slates, soft phyllites and a banded iron ore formation. The dolomitic composition might denote an altered limestone, but dolomites are known to be, at times, derived by alteration from igneous rocks.

(B) IGNEOUS ORIGIN.

The rocks of the peridotite-pyroxenite group, classed by H. W. Turner[1] under the name Perknite, are known to occur sometimes as dykes, sheets, laccoliths, and small intrusive stocks, cutting or interbanded with Palæozoic and younger rocks, usually in a more or less altered condition.

Under the proper metamorphic agencies in the zone of weathering, peridotites and pyroxenites, or rocks of the perknite group, are known to break down to serpentine, with the separation of calcite, magnesite and silica, as shown by the following equations:

(1) $3CaMg\,(SiO_3)_2 + 2H_2O + 3CO_2 = 3CaCO_3 + H_4Mg_3Si_2O_9 + 4SiO_2$
pyroxene = calcite + serpentine + silica

(2) $2Mg_2SiO_4 + 2H_2O + CO_2 = H_4Mg_3Si_2O_9 + MgCO_3$
olivine = serpentine + magnesite

A whole list of possible changes might be presented as equations, but the above two illustrate the common change.[2]

[1] Journal of Geol., Vol. 9, 1901.

[2] See U.S.G.S., Mono. XLVII, Treatise on Metamorphism.

Serpentine, in turn, is broken up or desilicated as follows:

(3) $H_4Mg_4Si_3O_9 + 3CO_2 = MgCO_3 + 2SiO_2 + H_2O$
serpentine = magnesite + silica

We have all gradations from fresh unaltered igneous rock to the completely altered end product, made up of calcite, magnesite, dolomite and a few secondary silicates such as talc and muscovite mica. Pyroxenite-peridotite rocks and their first alteration products have been described by several writers. An example may be taken from the description of pyroxenite-serpentine areas in the Dun Mountain district, New Zealand, by A. N. Finlayson in Vol. 65, Q. Jr. G. S. The intrusive rocks are of Mesozoic age and appear more or less conformable in highly tilted slates and limestones.

The next stage is the alteration of the serpentine to the carbonates, etc. An example of this is found in the serpentine areas of the California Mother Lode, described ky F. S. Ransome in U.S.G.S. Atlas, folio No. 63.

> "Veins occurring in the serpentine area are characterized by conspicuous outcrops of massive white quartz. These quartz masses, however, constitute but a part of the whole vein, which may be 300 feet in width and usually consists of a more or less schistose aggregate of dolomite, mariposite (a bright green chromium mica), and talc. The quartz occurs as intersecting stringers or great thick lenticular bunches in this dolomitic mass, which is, without much doubt, an alteration product of the serpentine adjacent to the original fissure."

This serpentine is reported to be of Tertiary age. A significant fact is that both the serpentine and dolomite alteration product is present, as well as the chrome mica.

Returning to the areas in New Ontario, large masses of peridotite and serpentine have been reported as occurring in the Keewatin on the east side of Lake Temiskaming,[1] on the Montreal river[2], and on the shore of Abitibi lake.[3]

[1] M. E. Wilson in G.S.C., 1906. Map No. 1007.
[2] Ontario Bureau of Mines, 1909.
[3] Ontario Bureau of Mines, 1909.

Fig. II.

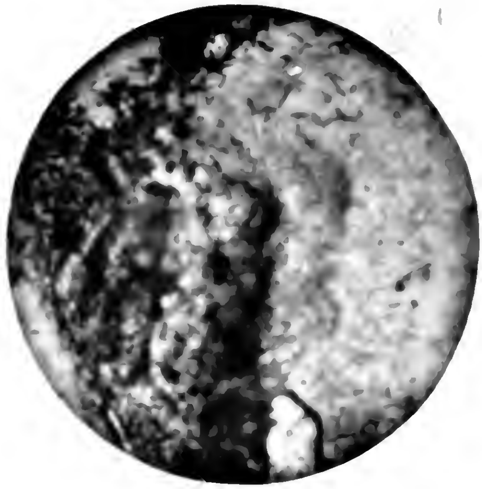


Fig. III

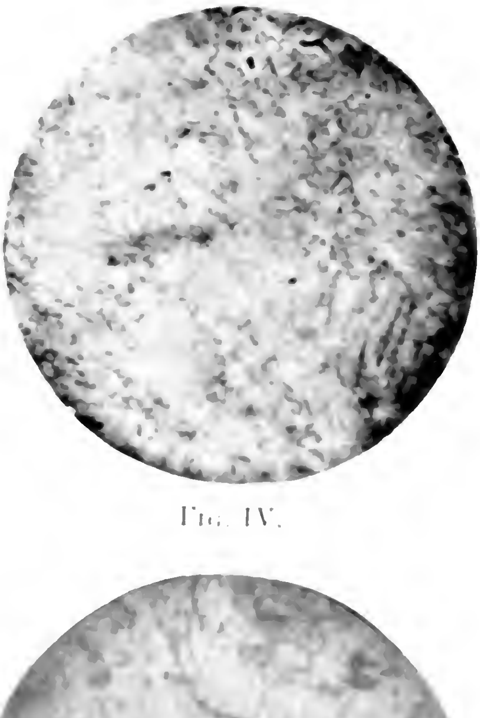


Fig. IV.

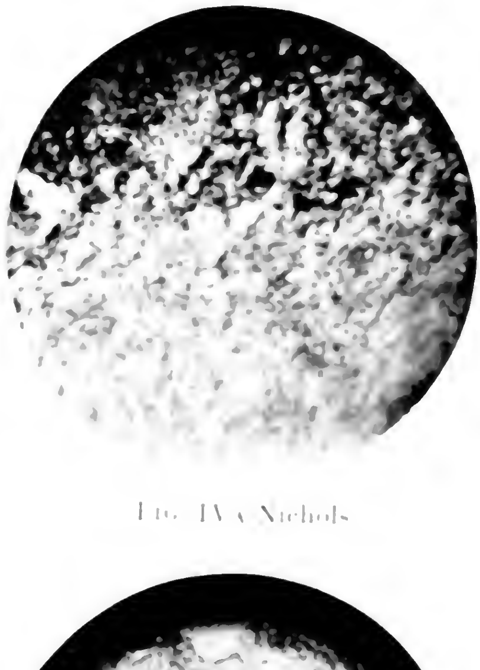


Fig. IV × Nichols

Fig. V

Fig. VI

Fig. VII.

Fig. VIII.

Fig. IX.

Fig. X.

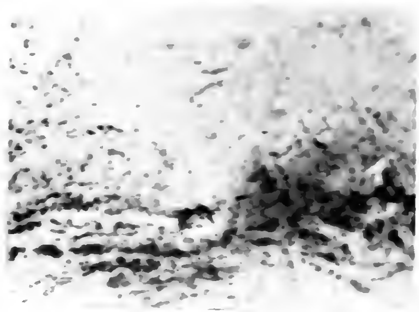


Fig. Xa.

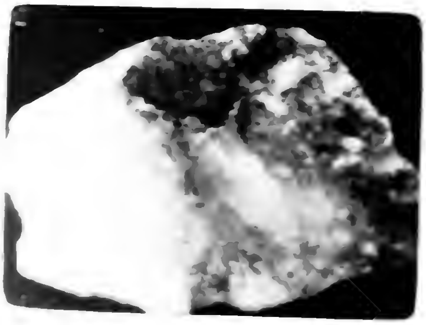


Fig. XI.

At the time these masses were intruded into the Keewatin sediments (?) and volcanics, in all probability dykes and sheets of the same material were formed by the molten magma forcing its way along lines of weakness, *e.g.*, bedding planes of the Keewatin strata. In no case are the bands, now observed, of very great width. The widest in the Larder lake area is about 300 feet Along the north shore of Larder lake there are a series of bands, seldom over 50 feet wide. They are more or less local and pinch out to the north-east and south-west. To the south of the lake there is another well-defined band striking north-west and south-east. It is exposed on the Valentine claim in Skead township. For the rest of its extent it is covered by a heavy overburden and cannot be traced.

The chemical composition suggests an altered basic rock. The presence of nickel in the band at the Harris-Maxwell mine and the general presence of chromium, replacing aluminium in the mica, is indicative of an igneous origin. Pirsson in his text-book on "Rocks and Rock Minerals," has the following to say about dolomitic rocks and talc schists:

> "The talc schists undoubtedly represent material which was sometines of igneous origin, peridotite, pyroxenite or dunite, and sometimes of sedimentary origin, dolomitic, ferruginous marls, etc. It may not be possible from field work, and an inspection of the specimens alone, unless aided by chemical analyses and microscopical study, to decide in any given case, which origin the material had, and sometimes not even then. The presence of chromium, either in the form of chromite or of secondary minerals derived from it, such as Kammererite or fuchsite (a variety of muscovite green from chromium), is indicative of igneous origin, while that of much talc . . . . would be, on the other hand, more indicative of a sedimentary origin."

SUMMARY OF POINTS IN FAVOUR OF IGNEOUS ORIGIN.

(1) Igneous rocks are known to form conformable bands with other rocks, in the form of sills, sheets and dikes.

(2) The basic igneous rocks are known to break down (de-silication) in the zone of weathering to simpler silicates and carbonates.

(3) Chromium is a characteristic constituent of basic rocks, especially ultra basic rocks.

(4) Nickel is present in finely divided form, only in igneous rock.

(5) Comparison with other areas gives some idea of the changes that go on to produce a rock such as the green dolomite.

(a) Peridotite-pyroxenite rocks of the Dun Mountain areas, New Zealand, altered to dunite and serpentine. (Mesozoic.)

(b) Serpentine of the California Mother Lode altered to magnesite, ankerite, dolomite, silica and chrome mica. (Tertiary.)

(c) Completely altered serpentine to massive magnesite and chrome mica, reported by R. G. McConnell from the Yukon. (Age not noted.)

CONCLUSION.

The changes a rock of the peridotite-pyroxenite group undergoes to the final stage, where all the original minerals have been desilicated, have been followed in examples of rocks considerably younger than the Keewatin. It follows, then, that we could expect the same kind of rock, of Keewatin age, to be entirely changed, especially where it occurs in narrow bands. On the whole the evidence points more towards an igneous origin than toward a sedimentary one.

EXPLANATION OF FIGURES.

Figs. II and III.—Microphotos of the inclusions in the mica.

Figs. IV and IV*a*.—Microphotos of the section from the Harris-Maxwell band. Shows pseudomorph of calcite and quartz.

Fig. V.—A bit of mica in the same section.

Fig. VI.—Chromite altering to the green mineral. Also shows needles of tourmaline in quartz.

Fig. VII.—Flake of mica showing isomorphous growth of the green on white.

Fig. VIII.—Contorted Mica Crystal (polished surface).

Fig. IX.—A crystal of the mica.

Fig. X.—Polished surface, showing the mica along the schistosity.

Fig. X*a*.—Same surface as X after being etched by cold dilute hydrochloric acid.

Fig. XI.—Polished surface showing the green mica (dark), quartz, and specks of gold in the quartz. (Reddick mine.)

GENERAL INDEX.

NOTE—The names of Authors of papers are here printed in small capitals, and the titles of papers in italics.

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